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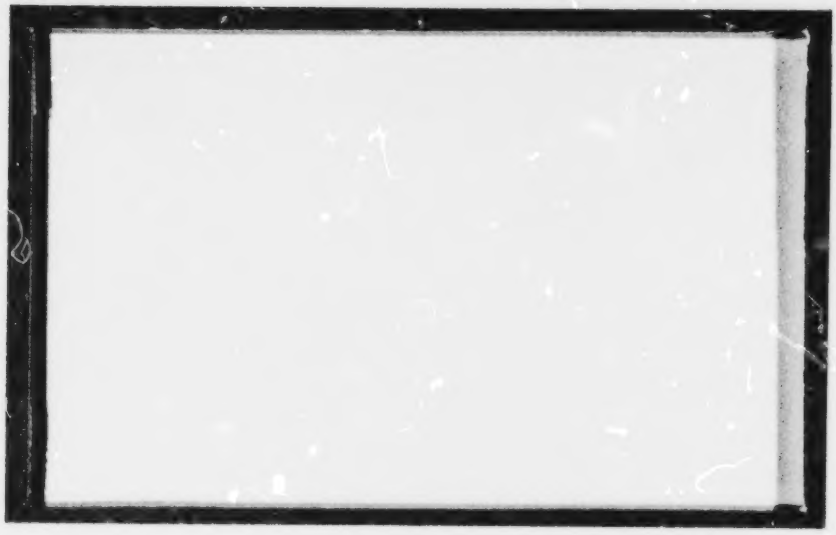

CENTRE DE RECHERCHE SUR LES TRANSPORTS

CASE POSTALE 6128, STATION A, MONTRÉAL, QUÉBEC, H3C 3J7

VALIDATION AND APPLICATION OF EMME: AN EQUILIBRIUM BASED TWO-MODE URBAN TRANSPORTATION PLANNING METHOD

by

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This project was developed with funding provided under the terms of a research contract with Transport Canada.

Paper prepared for presentation at the TRB Conference, January 1979.

Université de Montréal
Publication # 103 - Centre de recherche sur les transports
Juillet 1978

Dépôt légal - 3e trimestre 1978

1. INTRODUCTION

The purpose of this paper is to report on the validation and application of the two-mode urban transportation planning technique denoted EMME (Equilibre Multi-Modal/Multimodal Equilibrium). This method which may be characterized as an integrated two-mode traffic equilibrium method has been suggested by Florian [6]. Roughly speaking, this method combines a zonal aggregate demand model (which may be a direct demand model or an O-D table coupled with a suitable modal split function) with an equilibrium type road assignment and a transit assignment method. The method has been described previously in [7] and some of its theoretical properties have been further studied by Fisk and Nguyen [5]. The basic model and algorithm are given in the Appendix. The model was validated by using data originating from the city of Winnipeg, Manitoba, Canada. The equilibrium type route choice model for travel by private cars in congested urban areas was validated by Florian and Nguyen [8] in the Winnipeg road network. The transit assignment model is essentially a shortest route choice coupled with the diversion mechanism among sections served by common lines devised by Chriqui and Robillard [4].

In the summer of 1976 the City of Winnipeg carried out a speed/delay study which consisted of measuring link volumes and link auto travel times for 80 - 90% of the street system. In addition, bus travel times were measured for 446 transit lines sections. This data served to re-calibrate the volume/delay curves that were used in the road assignment and to calibrate the bus/auto travel time relationship required by EMME.

Since the city of Winnipeg did not previously use a transit assignment model, the transit network was coded according to the EMME specifications described by Achim and Chapleau [1] that permit the interface between the road and transit networks.

The bus/auto travel time relationships and the volume/delay curves were integrated with the coded road and transit networks and were used for the determination of the auto and transit origin/destination matrices.

During the summer of 1976, the City of Winnipeg carried out an origin-destination

of trips taken from home to work. A 17% sample of households was sampled and a separate survey of 23% of student trips was performed at about the same time. Since all the analysis is done for the 7:30 - 8:30 AM peak hour one of the first tasks considered was to define the so-called "departure codes", that is, the starting time of trips that will be using the road and transit networks during the peak hour. The departure codes were determined initially by the City of Winnipeg staff and were first specified by origin, using a subdivision of origins into 36 super zones. By using the departure codes, the corresponding trips are extracted from the survey data and multiplied by the appropriate expansion factors to obtain an estimate of the *total person work trips* taken in the peak hour by each mode. Then, the total auto work trip matrix is scaled by appropriate car occupancy factors in order to obtain the *total auto work trip* matrix.

This matrix was then assigned to the road network and compared with the observed link volumes. Since only the work trips are sampled during the O-D survey, it was necessary to develop a set of adjustment factors (or factors) that multiply the number of trips in the *total auto work trip* matrix in order to reflect auto trips that are taken for other purposes than work and a certain amount of truck traffic. These factors are specified by origin for a subdivision of origins into 10 super zones. The determination of the most appropriate factor is a trial and error procedure, where a factor is tried, the resulting assignments are compared to observed link flows and then a new factor is determined which is hopefully more appropriate. Five factors were tried until satisfactory results were obtained. In addition, it turned out that trips to the University of Manitoba (zone 59) required special departure codes, which were specified for the subdivision of origins into 10 super zones, since this zone is relatively more distant from most origins. In the EMME computer system, the factors are converted into a *vehicle adjustment trip matrix* which is added to the *total auto work trip* matrix for the purpose of the assignment.

Once the departure codes, and hence the fixed O-D matrices were determined, the modal split function was calibrated. Due to the large size of the sample it was possible to calibrate a zonal aggregate logit type modal split function, which is of the well known general form

$$P_r(\text{bus}) = 1/1+\exp(K_o+\sum_i K_i X_i)$$

where K_o and K_i are calibrated from the data and X_i are the independent explanatory variables. A very large number of trials were carried out and they are described in detail in Section 6 of this paper.

The best results were obtained by subdividing the origins into 4 subgroups, which were determined by exploratory data analysis, and calibrating a modal split function for each subgroup.

We were then provided by the City of Winnipeg with a road improvement scenario and a transit improvement scenario. We first analyzed the base year calibration by using the bi-modal model and then proceeded to analyze the impact of the scenarios.

In the sections that follow we describe in detail the technical work done on each part of this project and give the results of the simulations made for the improvement contemplated. The results that we obtained are very good and demonstrate the utility and viability of the method.

2. THE BUS/AUTO TRAVEL TIME FUNCTION

The purpose of this task of the project was to develop a model that relates the travel time of a transit vehicle on a road link to the corresponding travel time for private cars. The model is used to take into account the change of transit travel times, as a result of a change in the congestion level of a road link.

The data that were needed to develop this model are road link lengths, observed car travel times on those links, and the corresponding bus travel times. The road link lengths and car times were obtained from the road network data. The City of Winnipeg provided us with observed bus travel times for line sections (a line section is considered to be defined as the sequence of the corresponding road links).

We first created a data file, using the data provided to us by the City of Winnipeg, that contains for esch line section, the following information:

- starting node
- ending node

. direction (inbound or outbound)
. line number
. observed bus time
. observed car time (for the complete sequence of links)
. minutes per mile for the bus on the section
. minutes per mile for cars on the section
. number of road links in the section

The file contains observations for 470 line sections. On 25 segments, the observed transit time was smaller than the observed car time. Since this problem seems to be related to the accuracy of the data, these observations were not considered in the calibration of the model.

We first introduce some notation: let

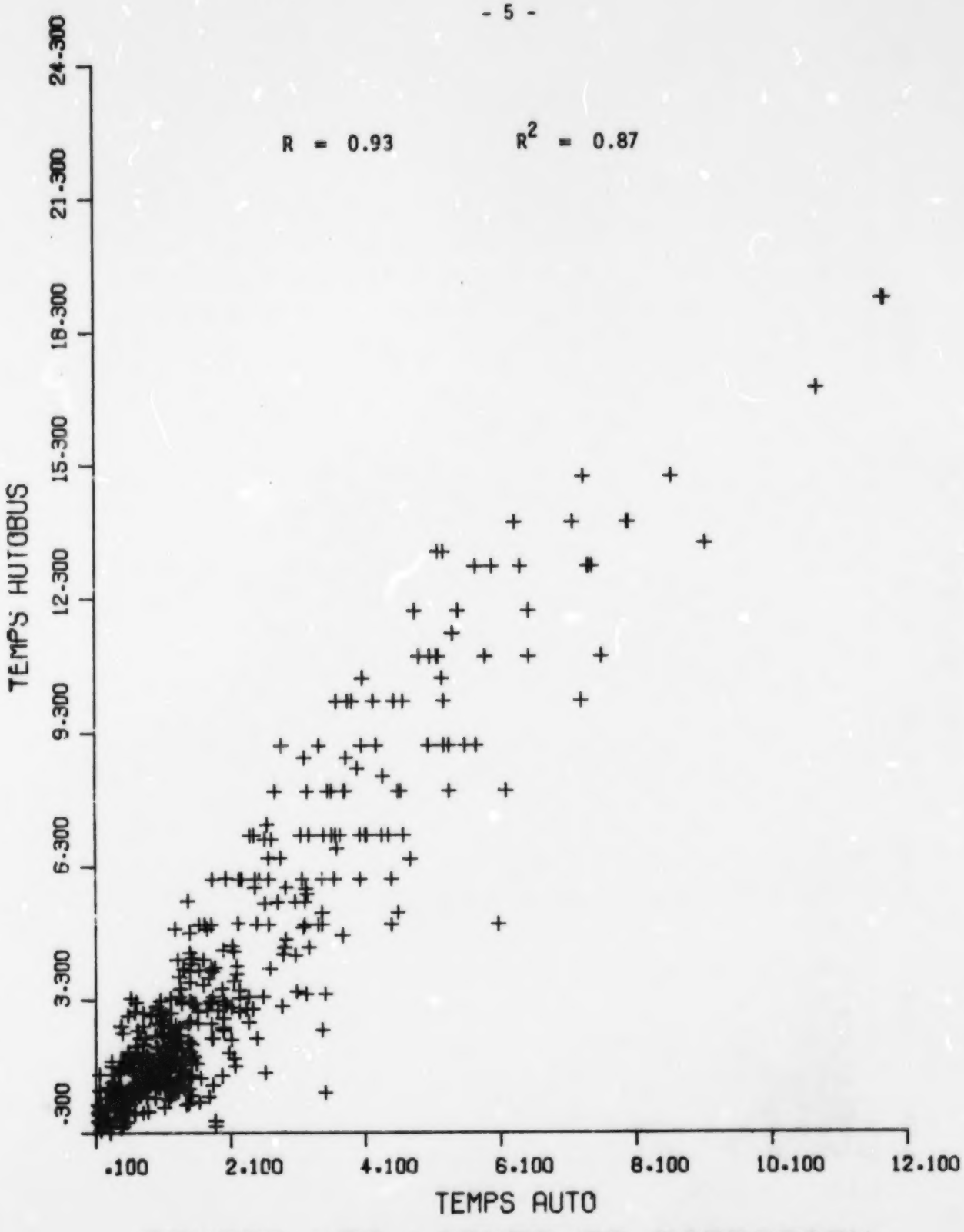
TA : auto time on the line section (minutes)
TB : bus time on the line section (minutes)
TMA: auto time per mile on the line section (minutes/mile)
TMB: bus time per mile on the line section (minutes/mile)

First, we plotted TB as a function of TA. Figure 2.1 shows the resulting scatter diagram; a linear function was fitted resulting in an R^2 of 0.87. However, some contemplation of this relationship reveals that over long sections, both the car and the auto times are relatively long, and, of course, on short sections, both times are relatively small (that is they are both correlated to link length). Evidently, such a model would not capture any effect of congestion.

We proceeded then to analyze the inverse of speed, time/mile, (which is used in the formulation of volume-delay curves). A simple linear model of TMB vs TMA resulted in a poor fit of $R^2 = 0.2$. A linear model of TMB vs TMA and TA, increased the R^2 to 0.49 which, again, was not satisfactory. In both of the above cases, we tried different models for the inbound and outbound direction but the fits, reflected in the R^2 values, were not improved.

A plot of (TB/TA) vs TMA showed that a nonlinear model could be more appropriate (fig. 2.2). An exponential model of the form

$$\ell n\,[\,(TMB/TMA) - 1] = a_0 + a_1\,TMA$$


R = 0.93
R^2 = 0.87
TEMPS AUTOBUS
24.300
21.300
18.300
15.300
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3.300
.300
.100
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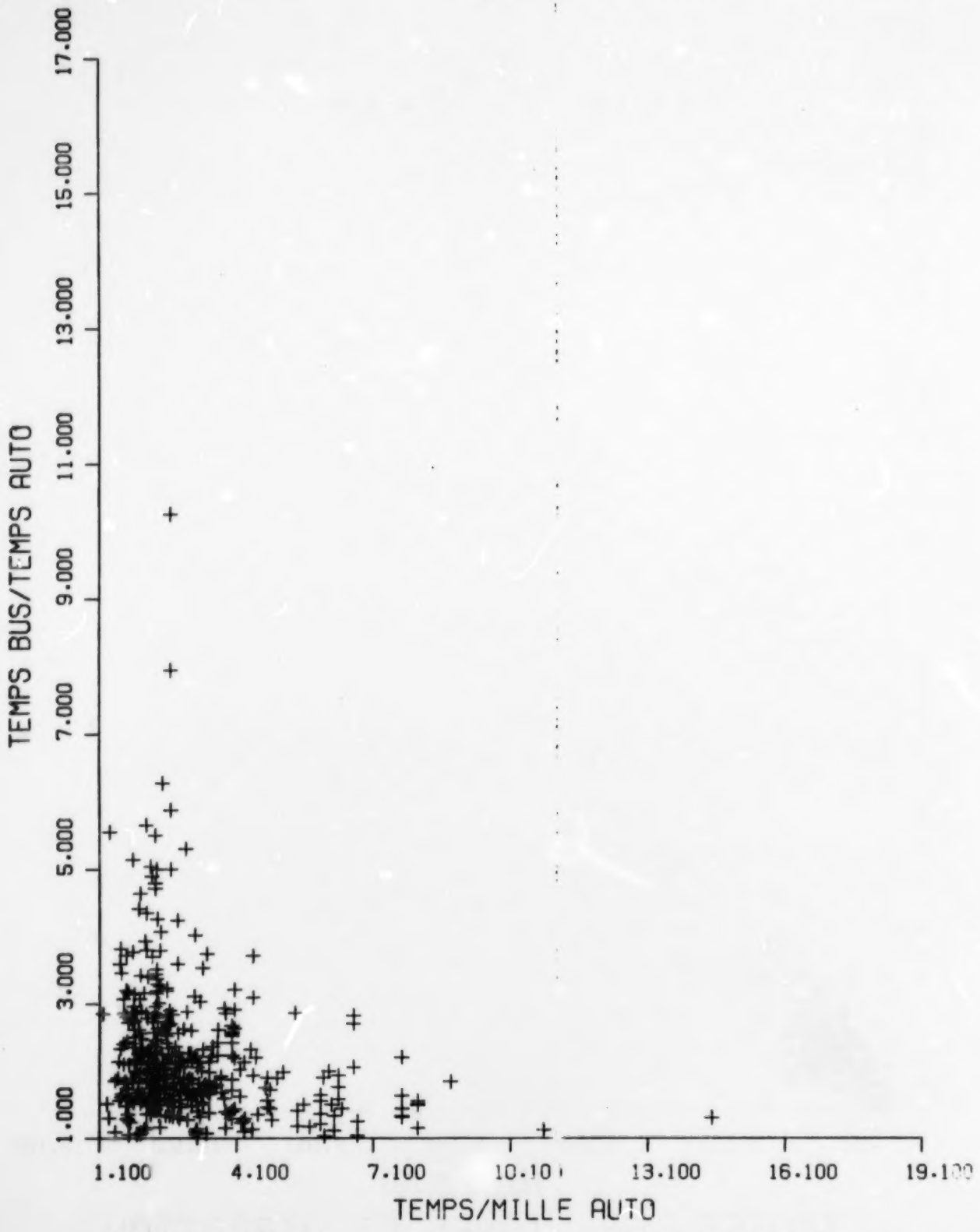
TEMPS AUTO
TOUTES LES LIGNES ET DIRECTION

Figure 2.1



TOUTES LES LIGNES, TOUTES DIRECTIONS

Figure 2.2

was estimated by linear regression. Again, with an $R^2 = .09$, the model was rejected. We then attempted to use a polynomial model of the form

$$(TMB/TMA) - 1 = a_1 (TMA)^{-1/2} + a_2 (TMA)^{-1} + a_3 (TMA)^{-3/2} + a_4 (TMA)^{-2}$$

which was estimated with a stepwise linear regression. The only term that entered in the regression was $a_1 (TMA)^{-1/2}$ and it resulted in an R^2 of .62 which, considering the accuracy of the data, was the first satisfactory result obtained. The analytical form of this model, which we shall call M1, is:

$$(TMB/TMA) - 1 = 1.97 \sqrt{1/TMA}$$

or

$$TMB = TMA + 1.97 \sqrt{TMA} \qquad (M1)$$

As an alternative, we considered a linear model of the form $TMB = m \cdot t_o + TMA$, where t_o is the inverse of the free flow speed of the road link. t_o values were obtained from the road network data. A linear regression gave an R^2 of .62; the model, denoted M2, is as follows:

$$TMB = TMA + 1.43\, t_o \qquad (M2)$$

where $1.43\, t_o$ is a constant penalty in minutes per mile for transit vehicles, which is related in some way to the link type.

The next step was to make an evaluation of the predictive ability of models M1 and M2. Since we are mainly interested in predicting good transit impedances (origin to destination path times), we decided to compare for each line and each direction in the data file the sum of the predicted travel times on each section against the corresponding observed times. The results were good for most of the lines (within 10%) except for express services and for some high speed regular lines.

It then became evident that a natural way to improve the models was to stratify the data according to service type. The three types considered were:

- feeder (0 observations in data file)
- regular (426 observations)
- express (44 observations)

Models of the same form as M1 and M2 were estimated for the express service.

The R^2 were close to 0.5 and the models were not significant because of the rather small number of observations available. In the case of regular service, the recalibration of models M1 and M2 resulted in the relations:

$$TMB = TMA + 2.1 \sqrt{TMA}$$
$$TMB = TMA + 1.49\ t_o$$

The R^2 improved slightly (0.64) but overall, the models did not change significantl We then subdivided the regular service into two categories by considering the average observed speed of each line. All the lines running below 10 mph were classified as "regular" and the others as "fast regular".

For the "fast regular" lines, the recalibration of the model M1 results in

$$TMB = TMA + 2.15\ ,\ R^2 = .84$$

and of the model M2 in

$$TMS = TMA + 0.9\ t_o\ ,\ R^2 = .84$$

For the regular lines, model M1 becomes

$$TMB = TMA + \frac{9.14}{\sqrt{TMA}}\ ,\ R^2 = .78$$

and the model M2 becomes

$$TMB = TMA + 2.12\ t_o\ ,\ R^2 = .73$$

This time the comparison, for each line and direction, of the sum of observed and predicted times on each section showed that $TMB = TMA + 2.15$ is a good model for fast regular lines. In the case of regular lines, both models had to be rejected. Our next step in the analysis of the regular lines was to go back to the previous form of the model, that is, to estimate a function of the form

$$TMB = TMA + \alpha\sqrt{TMA}$$

which had proved to be satisfactory for regular lines, except for the fast ones. The estimation resulted in an $\alpha = 3.21$ and an $R^2 = .73$. Unfortunately, the comparison of the sum of line section times showed that the previous model ($\alpha = 2.1$, $R^2 = .64$), which had been estimated on all regular lines data (fast regular + regular), gave better results that the new one which had been estimated on by using data for regular lines (< 10 mph) only !

All the above analysis suggested that it may be advantageous to define fast regular lines by using a higher speed value. But, further experiments indicated that the results could not be improved in this way.

Considering the above analysis, and the fact that we did not have sufficient data for feeder and express services, we finally selected and implemented the following bus travel time relationships:

. On transit-only links, the user-defined travel times are used. On transit links corresponding to road links four cases are considered:

. For a feeder service (line type 3) the user-defined line speed is used on all links, independently of car speed.

. For an express service (line type 1) the bus speed is the same as car speed: TMB = TMA.

. For a fast regular service (line type 2) we have: TMB = TMA + 2.15 (regular lines with a commercial speed of 10 mph or more were considered as fast lines).

. For a regular service (undefined line type) we have:
TMB = TMA + 2.1 * $\sqrt{TMA}$
where TMB = minutes by mile for bus
TMA = minutes by mile for automobile.

We were now ready for the final part of this task, which was the evaluation and fit of the bus/auto travel time model on the complete Winnipeg transit network. The relationships were applied to predict the transit travel time on each of the 1755 transit links of the coded network. On the basis of those predicted times, transit paths between selected O-D pairs were calculated. An analysis of the transit times and paths suggested that we should change the classification (type) of some of the lines. After a few iterations of this procedure, we finalized the classification for all of the lines.

We would now like to conclude with the remark that an important fringe benefit of having included a bus time model in EMME is that the user does not have to define a travel time for each of the transit links; thus the coding of the network is made much easier.

3. RECALIBRATION OF THE VOLUME/DELAY CURVES

The volume/delay curves used by the City of Winnipeg were developed in the early sixties by Traffic Research Corp. and had the functional form

$$S_a(v_a) = d_a\{\delta + \alpha\,(\frac{v_a}{\ell_a} - \gamma) + (\alpha^2\,(\frac{v_a}{\ell_a} - \gamma)^2 + \beta)^{1/2}\}$$

We modified this functional form by replacing it with the simpler BPR formula:

$$S_a(v_a) = d_a\, t_o\, \{1 + \alpha\,(\frac{v_a}{c_a})^{\beta}\}$$

where d_a is the link length, v_a is the link volume, ℓ_a is the number of lanes of the link, c_a is the practical capacity of the link and the other parameters are calibrated from the observed data.

The initial transformation was done by Branston [3]. He estimated a practical capacity for each of the TRC volume/delay curves and then calibrated the constants α, β of the BPR formula by using the predicted times of the TRC functions. The results of the calibration are shown in Figures 3.1 to 3.4. The solid lines show the BPR curve and the points indicate the times predicted by the TRC functions.

We then proceeded to recalibrate the BPR curves obtained in this way by using the 1976 data and the following procedure. For each volume / delay curve, the observed data was aggregated by using a subdivision of the link volumes v_a into intervals, and mean values were computed for each interval. The curves and the resulting mean values of the travel times were plotted and analysed; as a result, new free flow speeds were determined and then, the curves were replotted. This procedure was repeated three times, resulting in a new set of α, β and t_o. Table 3.5 shows the values that were actually used.

It was evident from the plots used to determine the free flow speed, that for certain links, that exhibited observed times below and to the right of the curves, would be better predicted by delay curves representing higher capacity links. In order to assist the City of Winnipeg in this reclassification of links to different curves, a report was produced for all links for which an observed flow was available. This report gives the time predicted by the currently

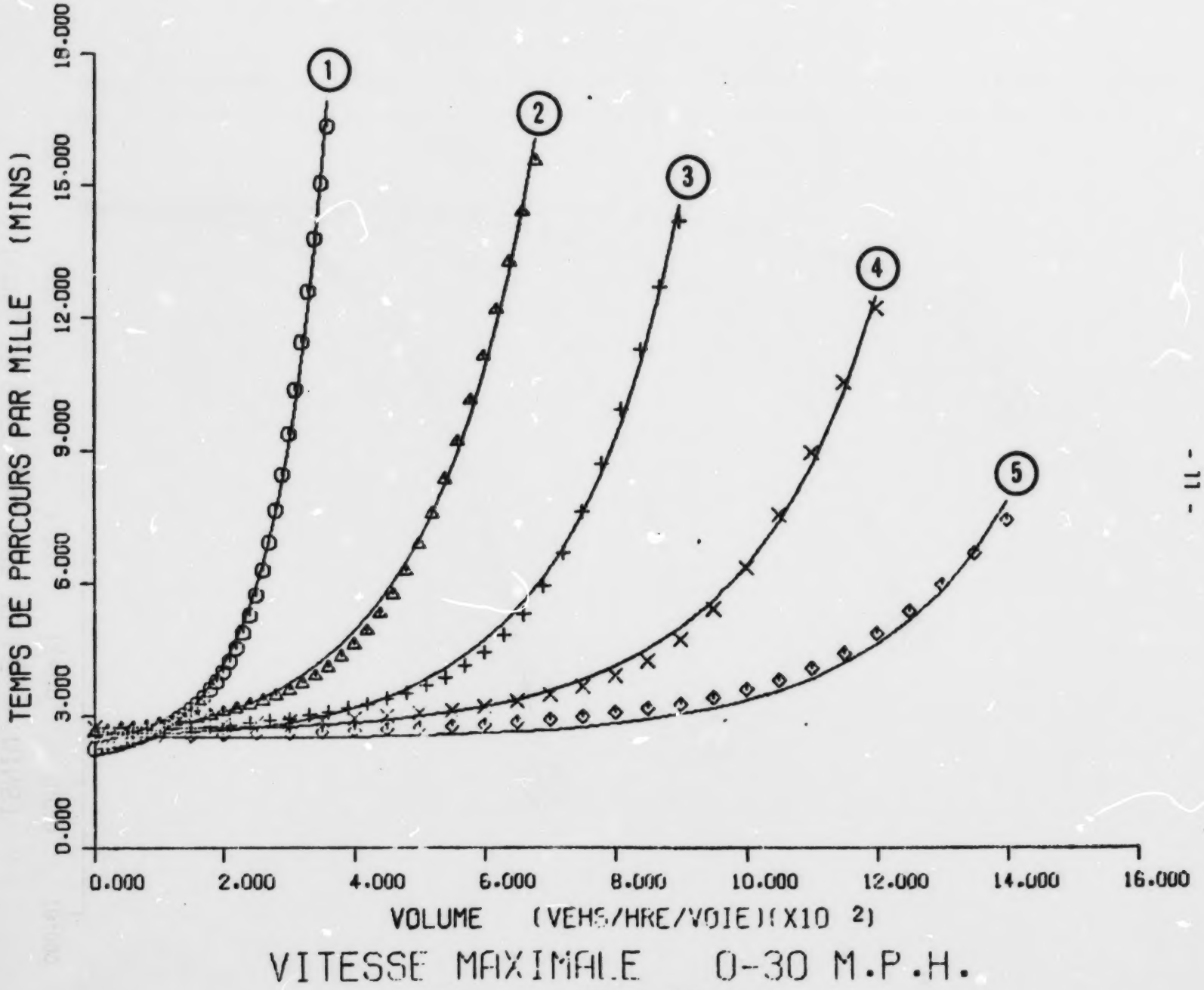


Figure 3.1 - TRC vs. BPR curves

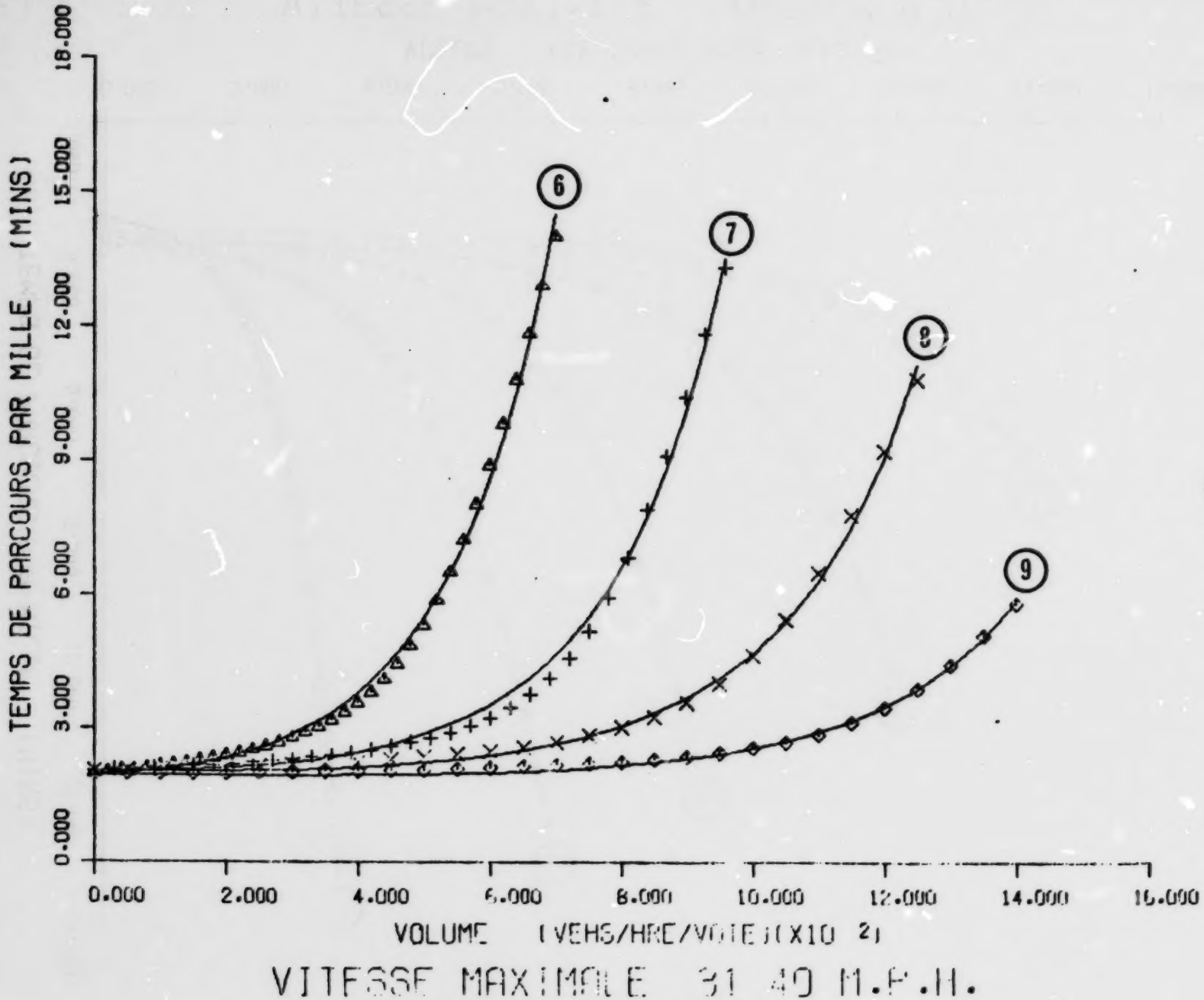


Figure 3.2 - TRC vs. BPR curves

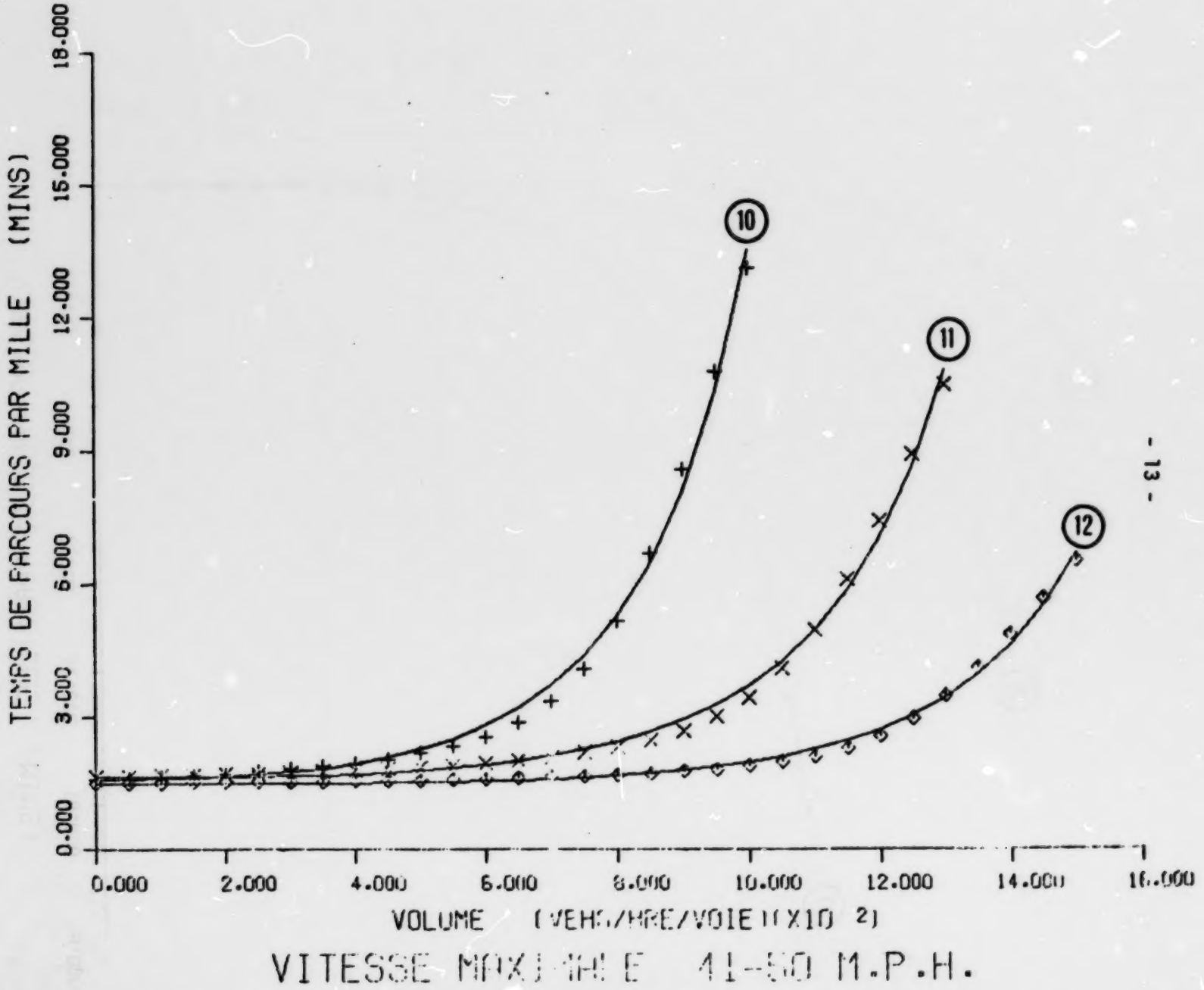


Figure 3.3 - TRC vs. BPR curves

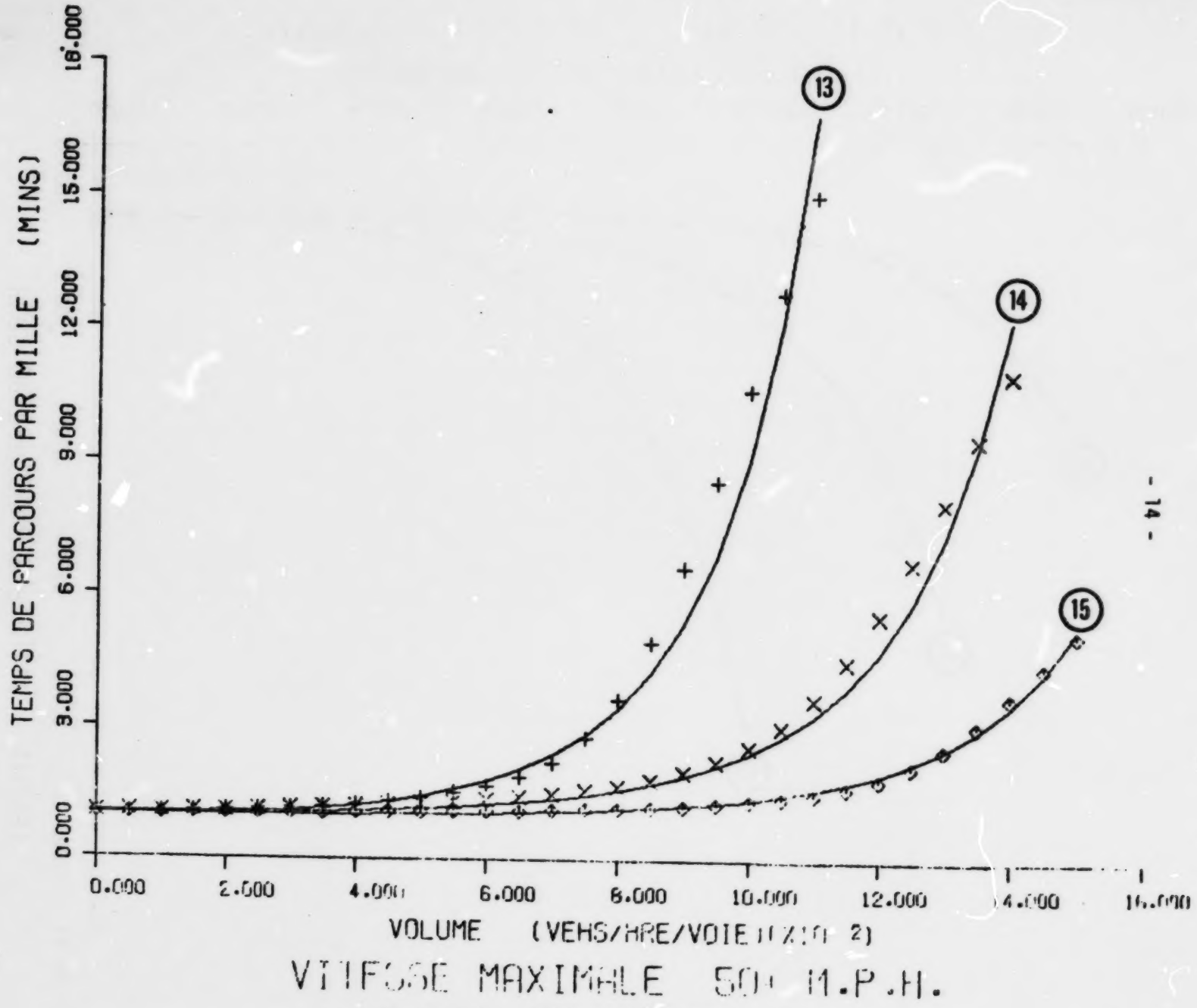


Figure 3.4 - TRC vs. BPR curves

assigned curve and also other curves which would predict the travel time better while respecting the speed limit. This report was used to reclassify links on a route basis. Links with large differences between predicted and observed times were plotted on a map in order to determine the links of an avenue or street that had to be reclassified. In some cases the number of lanes was corrected as well. This analysis also resulted in the correction of some observed travel times and volumes. In total, 159 links were reclassified, the number of lanes was changes for 23 links, the observed time updated for 192 links and the observed volume updated for 21 links.

4. CALIBRATION AND VALIDATION OF THE ROAD NETWORK ASSIGNMENT

The calibration of the road network was achieved by comparing the observed link volumes with the link volumes predicted by the traffic assignment model. The comparison is performed by using specially written programs and manually, by comparing screen line totals for the observed and predicted flows. Discrepancies between observed and predicted values may be caused by the errors introduced in the total auto O-D matrix or by improper coding of the road network. Since the 1976 road network differs little from the 1971 network, which was very carefully calibrated, the corrections necessary to the coding of the road network were all found during the re-calibration of the volume-delay curves and most of the adjustments made involved the total auto O-D matrix.

This matrix is calculated from the total person work trip matrix by using the observed modal split and car occupancy matrices and a set of adjustment factors that serve to add other purpose trips and truck trips; that is

$$g_{pq} = \frac{g_{pq} * r_{pq}}{\gamma_{pq}} * f_{pq}$$

where (p,q) is an origin-destination pair of zones

g_{pq} is the total person work trips between q and p

r_{pq} is the proportion of trips by automobile

γ_{pq} is the auto occupancy

f_{pq} is the factor for other trips and truck trips

The factors f_{pq} are given as a matrix of values for 10 groups of zones (super

CACO	SPEED LIMIT MPH	α	β	FREE FLOW TIMES/MINUTES PER MILE t_o
1	0-30	.7312	3.6596	15.0/4.00
2	0-30	.6128	3.5038	17.0/3.53
3	0-30	.8774	4.4613	20.0/3.00
4	0-30	.6846	5.1644	23.0/2.61
5	0-30	1.1465	4.4239	25.0/2.40
6	31-40	.6190	3.6544	30.0/2.00
7	31-40	.6662	4.9432	32.4/1.85
8	31-40	.6222	5.1409	32.4/1.85
9	31-40	1.0300	5.5226	35.3/1.70
10	41-50	.6609	5.0906	41.4/1.45
14	41-50	.5423	5.7894	41.4/1.45
15	41-50	1.0091	6.5856	41.4/1.45
15	+50	.8776	4.9287	55.0/1.09
16	+50	.7699	5.3443	55.0/1.09
18	+50	1.1491	6.8677	55.0/1.09

Table 3.5
Volume / delay functions

zones). The essence of the calibration procedure was a trial and error process that was aimed at finding the most appropriate factors based on the comparison of observed and predicted link volumes. While carrying this out 19 errors in the observed link volumes were detected and corrections were made.

All the factors in the calibration procedure were determined by the staff of the City of Winnipeg by using screen line counts. The screen lines chosen divide the city into three quadrants by using natural geographic subdivisions. A specially written program selects the links that cross each of these lines and provides the observed and predicted volumes, as shown in Figure 4.1, which are then totaled for each screen line.

First, an assignment was produced by using only the auto work trip matrix which is obtained by setting $f_{pq} = 1$. By relating super zone pairs with screen line crossings it is possible to adjust the various factors to increase or decrease the interchanges across the screen lines. The correspondence is as follows:

Quadrant	Super zones
1	1,2,3
2	4,5
3	Rest + downtown (0)

Various other considerations were taken into account in determining the factors f_{pq} such as the low production of truck trips by residential areas and high production of truck trips by industrial zones.

Another means to analyse the relation between the predicted and observed link volumes is given by a program which plots the predicted against observed link volumes and link travel times. See Figures 4.2 to 4.4. This program also produces an exception report which lists the links for which the predicted and observed times differ by more than 1 minute.

5. TRANSIT NETWORK VALIDATION AND CALIBRATION

This part of the project required considerable effort since the City of Winnipeg did not have, prior to this study, a transit network model and the work included the definition of the network, its coding, validation and calibration.

EMME WINNIPEG 1976 AM PEAK
FIXED DEMAND (5ZONE GROUPS)

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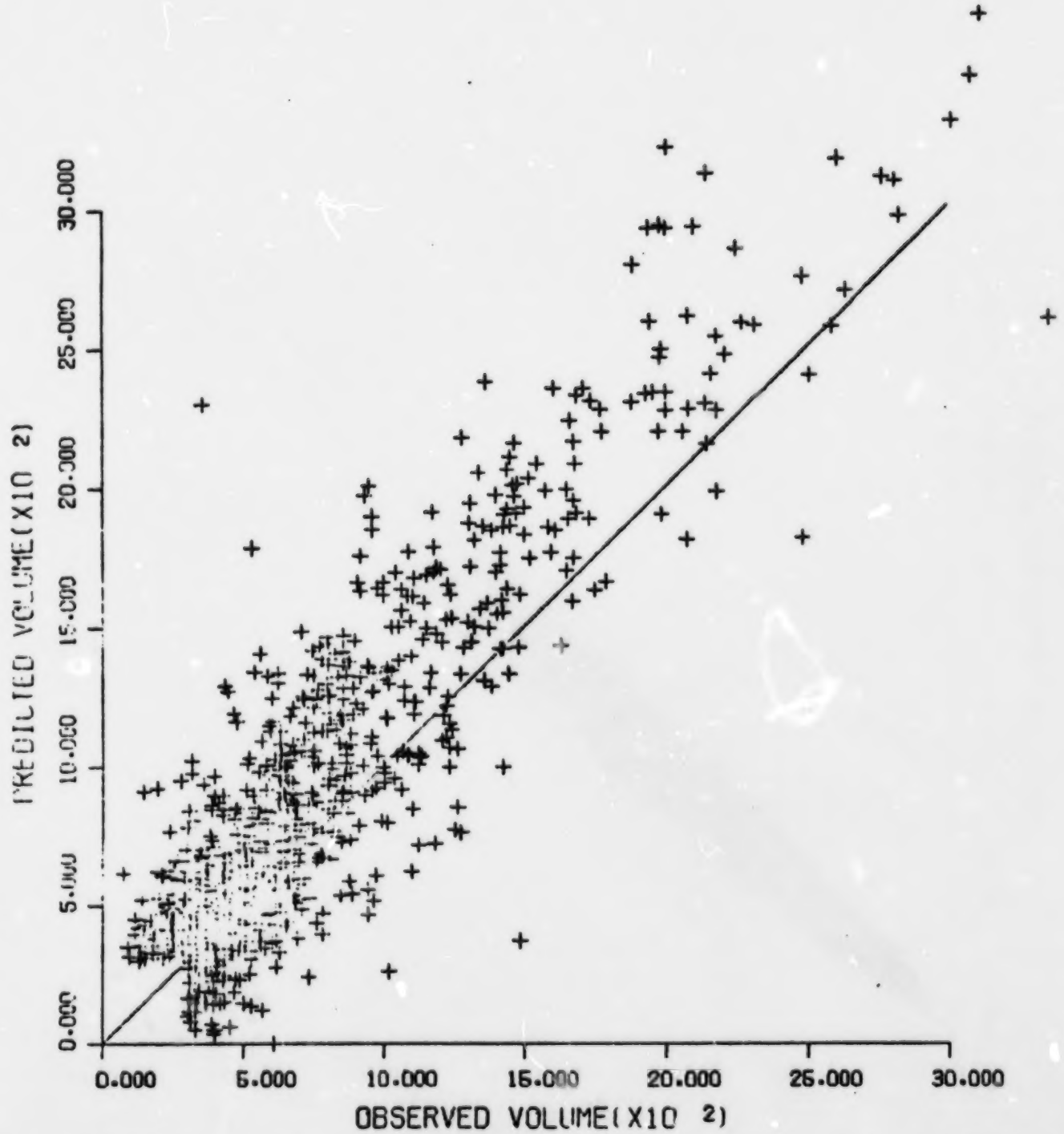
ROAD TRAFFIC ASSIGNMENT
CORRIDOR 0072

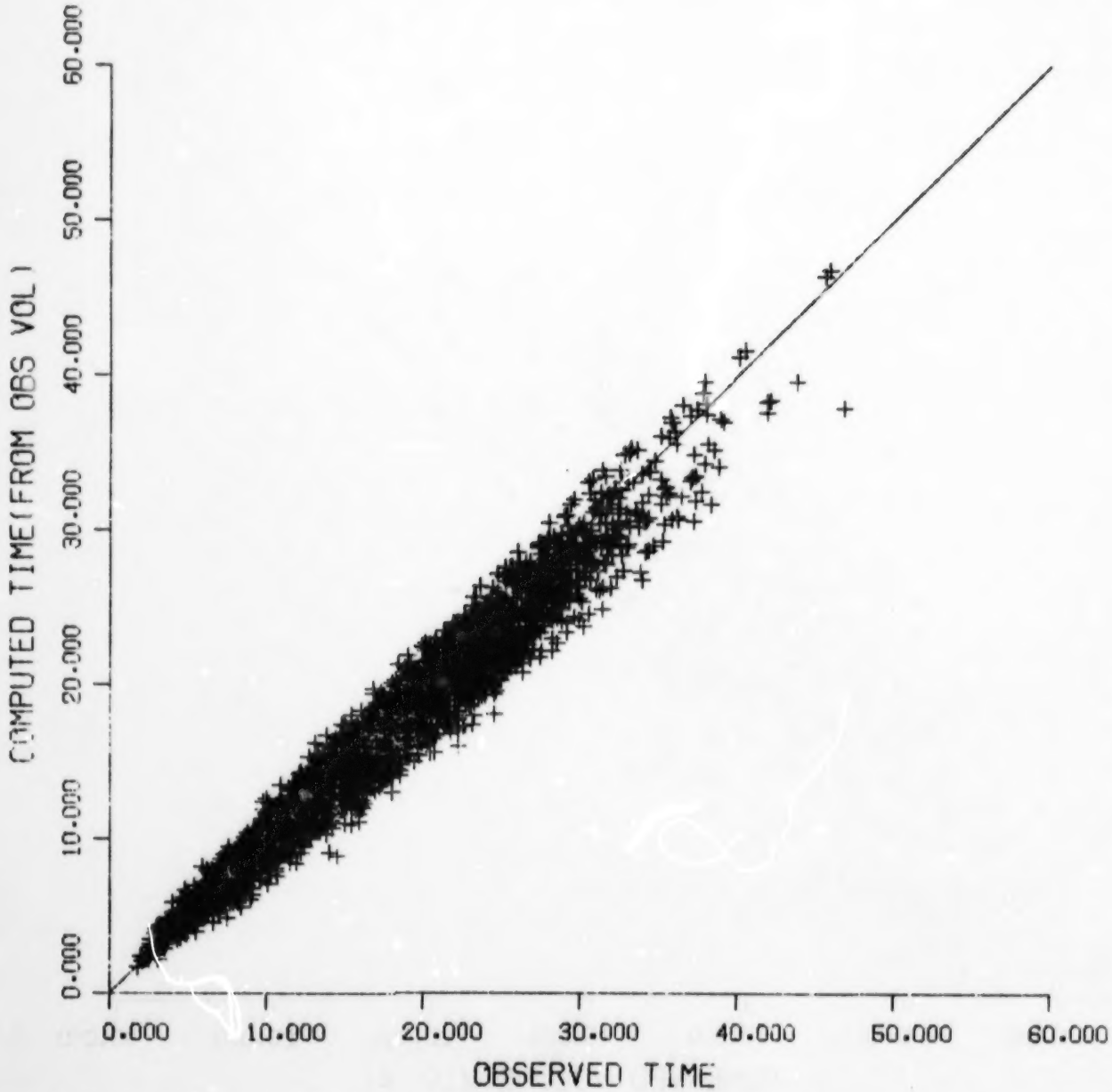
LINK	FROM	TO	LENGTH (MILES)	TYPE	FREE FLOW (MPH)	CAPACITY (VEH/HR)	OBSERVED TIME (MINS)	OBSERVED VOLUME (VEH/HR)	PREDICTED SPEED (MPH)	TRAVEL TIME (MINS)	AUTO VOLUME (VEH/HR)	LANES	BUS VOLUME (VEH/HR)
[illegible]													

Figure 4.1



WINNIPEG LINK VOLUME COMPARISON - 2 (1976)

Figure 4.2 - Assignment using Factor 8



WINNIPEG ROUTE TIME COMPARISON - 3 (1976)

Figure 4.3

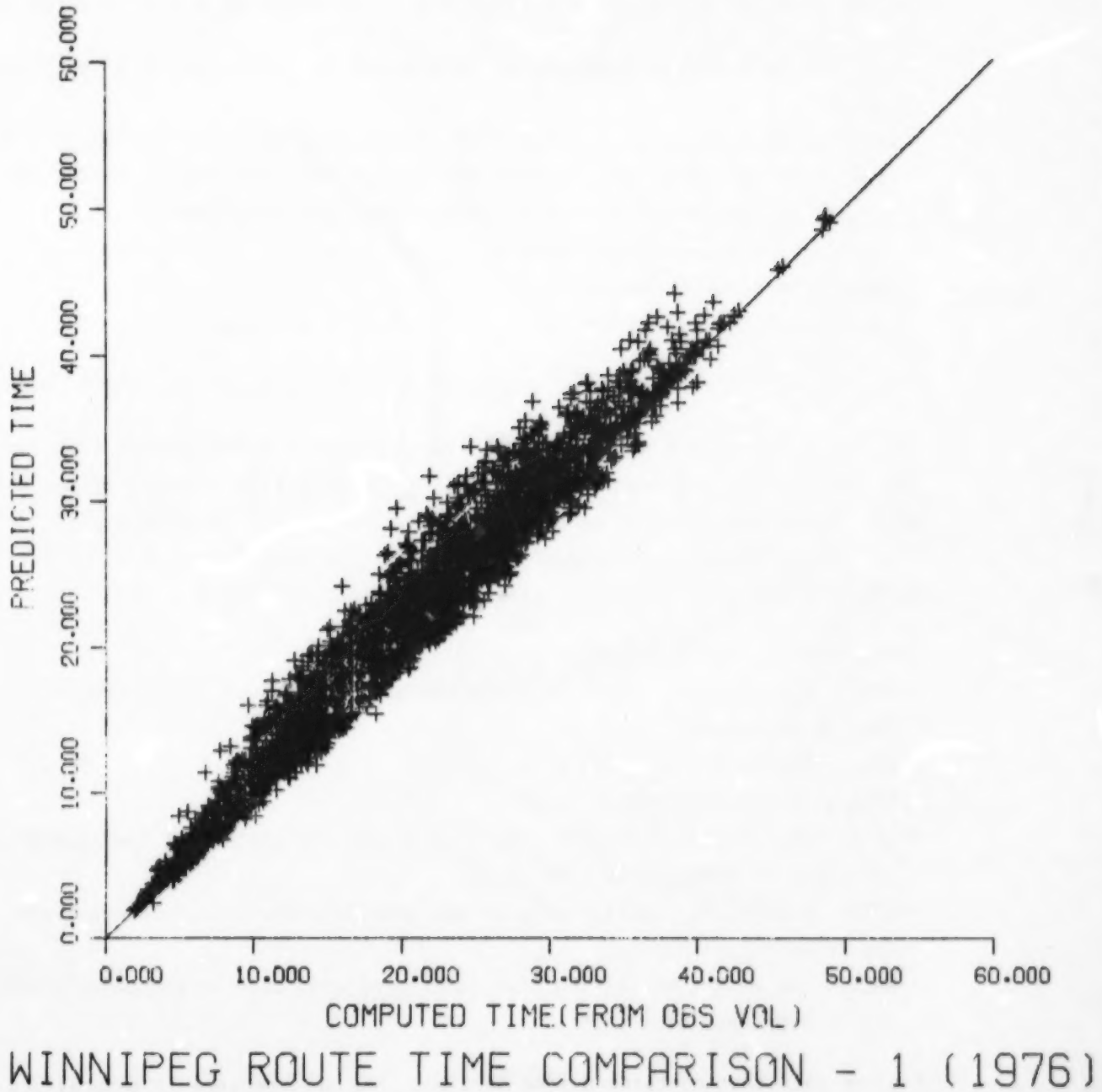

PREDICTED TIME
0.000
10.000
20.000
30.000
40.000
50.000
60.000
0.000
10.000
20.000
30.000
40.000
50.000
60.000
COMPUTED TIME(FROM OBS VOL)
WINNIPEG ROUTE TIME COMPARISON - 1 (1976)

Figure 4.4

The purpose of the validation is to make sure that the transit system is described properly. The coded network must represent adequately all the possible passenger movements on one hand and the transit vehicle movements on the other hand. The validation of the network consists then of ensuring that the coding rules have been followed correctly and that the representation of the two types of movements is satisfactory. The tools used in validation are:

- the EMME data bank programs which perform the syntactic and data consistency checks
- the network generation programs which ensure that the rigorous restrictions imposed on the input data in order to realise the interface with the road network and to determine transit travel times are satisfied
- graphical displays of the network
- manual checks of the data
- analysis of the complete print out of a transit assignment.

This taks was carried out in cooperation with the staff of the City of Winnipeg.

The calibration deals with the other aspect of the transit system, that is: the behaviour of the transit passengers in the selection of paths on the network. Given the shortest path behaviour hypothesis, it is necessary to estimate the value of certain parameters of the transit path algorithm in order for it to produce satisfactory paths between the various O-D pairs.

The parameters to be estimated are:

- WFAC , a regularity factor relating the waiting time to the headway of the line to be boarded
- WMIN , the minimum waiting time
- WMAX , the maximum waiting time
- WAIT , the weight of waiting time used in the calculation of the impedance of a path in generalized time units
- WPEN , a constant penalty added to the impedance every time the passenger has to wait for the bus
- WALK , the weight of walking time (access-egress) used in the calculation of the impedance of a path.

A given path that contains n line sections, has an impedance in generalized

time units, that is given by the expression:

$$IMP = WALK * (\text{access + egress time}) + WAIT * \sum_{\ell=1}^{n} w_\ell + \sum_{\ell=1} T_\ell + n * WPEN$$

where

. W_ℓ is the waiting time of the ℓ^{th} line defined as
  W min [max (WMIN, WFAC * HDW_ℓ) , WFAC * HDW_ℓ , WMAX]

. HDW_ℓ is the headway of the ℓ^{th} line and transfer time is considered as being included in waiting time.

. T_ℓ is the in-vehicle time spent on the ℓ^{th} line, which is assumed to have a wait of 1.0 in the impedance calculations.

For each O-D pair the algorithm selects the path with minimum impedance from origin O to destination D. The best way to calibrate the transit model would be to compare the predicted paths to the actual paths obtained from the O-D survey. Unfortunately, in the Winnipeg survey there was no question concerning the path used by transit riders. The method which we used consisted in analysing the predictions of a transit assignment, obtained with the observed O-D matrix by comparing it with the observed volumes on the segments and an occasional reevaluation of the observed transit O-D matrix. The analysis was made on level of service statistics (like mean total trip time, mean number of transfer, distribution of total trip time, etc.) and on predicted line volumes. Given the all-or-nothing aspect of the assignment, only large volumes may be analysed. The following volumes were analysed:

. the volume at the maximum load point of each line on both directions

. the location of the maximum load point

. volume profiles on lines

. screen line volumes
  - entering and leaving CBD
  - bridges
  - other high volume links

In the first stage of the analysis, three assignments were performed using the following parameters:

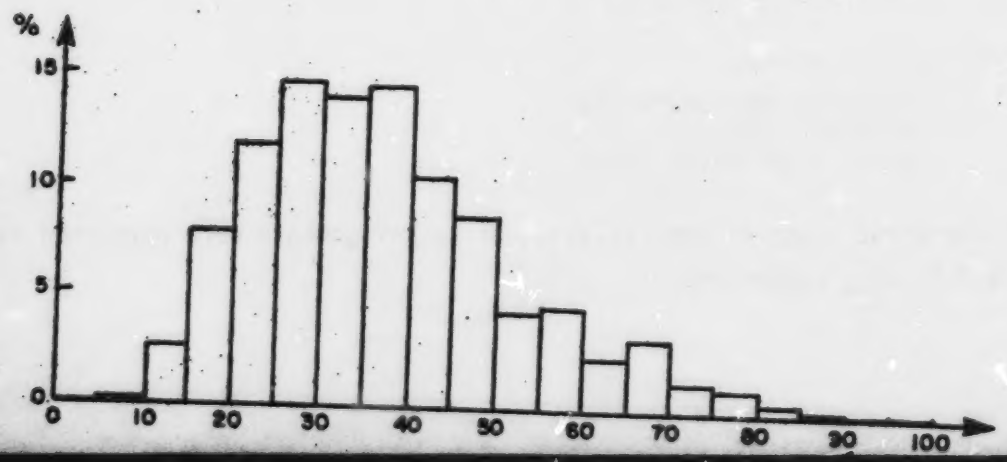
	WALK	WAIT	WFAC	WPEN	WMIN	WMAX
1 =	3.0	3.0	0.5	0.0	0.0	10.0
2 =	0.0	1.0	0.5	0.0	0.0	10.0
3 =	0.5	2.0	0.5	4.0	0.0	10.0

The analysis made by the staff of the City of Winnipeg showed that assignment number 1 was the best one but the split of volumes between competing lines was not satisfactory. We then introduced the "common line section" algorithm in the model. With this algorithm, the passengers are diverted over common bus lines proportionally to the frequency of each line (i.e. passengers are assumed to board the first line that arrives at the bus stop). We ran four new simulations with the following parameters:

	WALK	WAIT	WFAC	WPEN	WMIN	WMAX
4 =	3.0	3.0	0.5	0.0	0.0	10.0
5 =	0.0	1.0	0.5	0.0	0.0	10.0
6 =	0.5	2.0	0.5	4.0	0.0	10.0
7 =	0,5	3.0	0.5	4.0	0.0	10.0

Assignment number 4, which is similar to number 1, proved to be the best one and the spread of volumes had improved significantly.

The transit network contains 56 lanes and 1755 line segments. 57% of the road network nodes are used for coding the transit network as well as 198 nodes which are exclusive to the transit network. The total demand in the best year is 20,495 trips. The mean trip time is 36.85 minutes which is made up of 24.01 minutes in vehicle, 4.41 minutes of wait time and 8.53 minutes of access-egress. The distribution of total trip time is given by the histogram shown below.



6. CALIBRATION OF THE MODAL SPLIT FUNCTION

The basic data that was used for the calibration of the modal split function are the results of the O-D survey that was carried out by the City of Winnipeg in the spring and summer of 1976. The survey was carried out in large part by home interviews of a sample of 20% of households. The actual sample size obtained was roughly 17%, after refusals and rejects have been taken into account. In addition, a survey questionnaire to be returned by mail was distributed to the students of the three Winnipeg Universities; the effective sample of student trips was approximately 23%. The total sample, consisting of the individual detailed data, amounted to 52 424 questionnaires and this data was transmitted to us on a magnetic tape by the City of Winnipeg. Then, the 'departures codes' described earlier were applied in order to separate the trips that occur during the 7:30 - 8:30 AM peak. There were 17 761 individual records in the peak hour sub-sample. A detailed description of the data formats is given in Appendix 2.

The Impedance (Travel Time) Variables

The number of trips that occur during the peak hour were expanded by the proportion of the sample in each zone, that was calculated by the City of Winnipeg, in order to obtain the following O-D matrices:

- auto drivers and passengers (1) , auto drivers (1')
- transit passengers (2)
- total trips (3) = ((1) + (2))
- modal split (4) = ((1) / (3))
- car occupancy (5) = ((1) / (1'))

A summary by origin and destination of O-D matrices (1) and (2) are given in Figures 6.1, 6.2, 6.3, 6.4, while an average of (4) by origin and destination is given in Figures 6.5 and 6.6. (The auto drivers and passengers O-D matrix, shall be refered to as the auto O-D matrix). The auto O-D matrix was scaled by the appropriate factor to obtain the total auto O-D matrix and this last was assigned to the road network by using the equilibrium traffic assignment of EMME. The resulting origin to destination travel times constitute the O-D matrix of

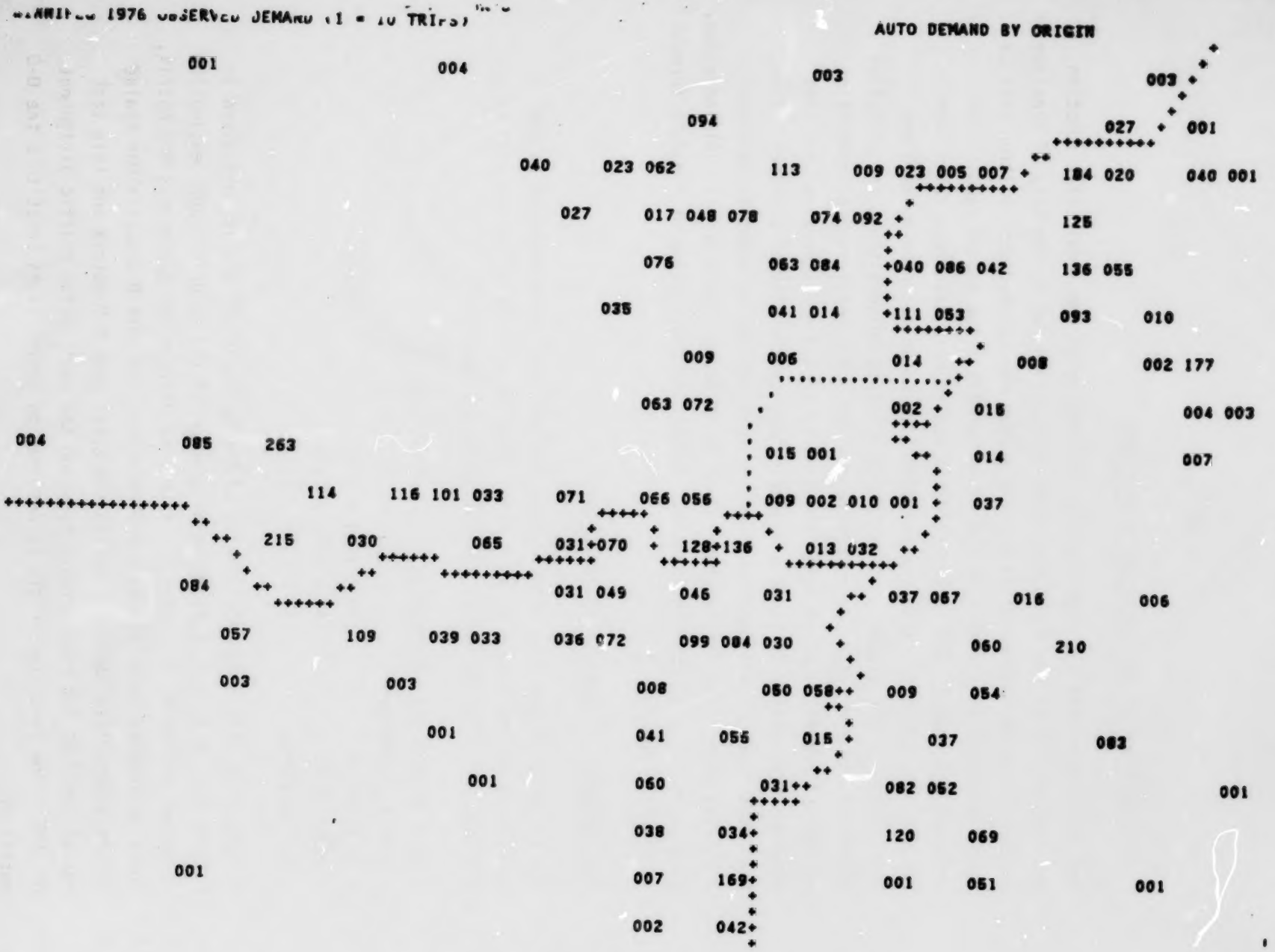


Figure 6.1

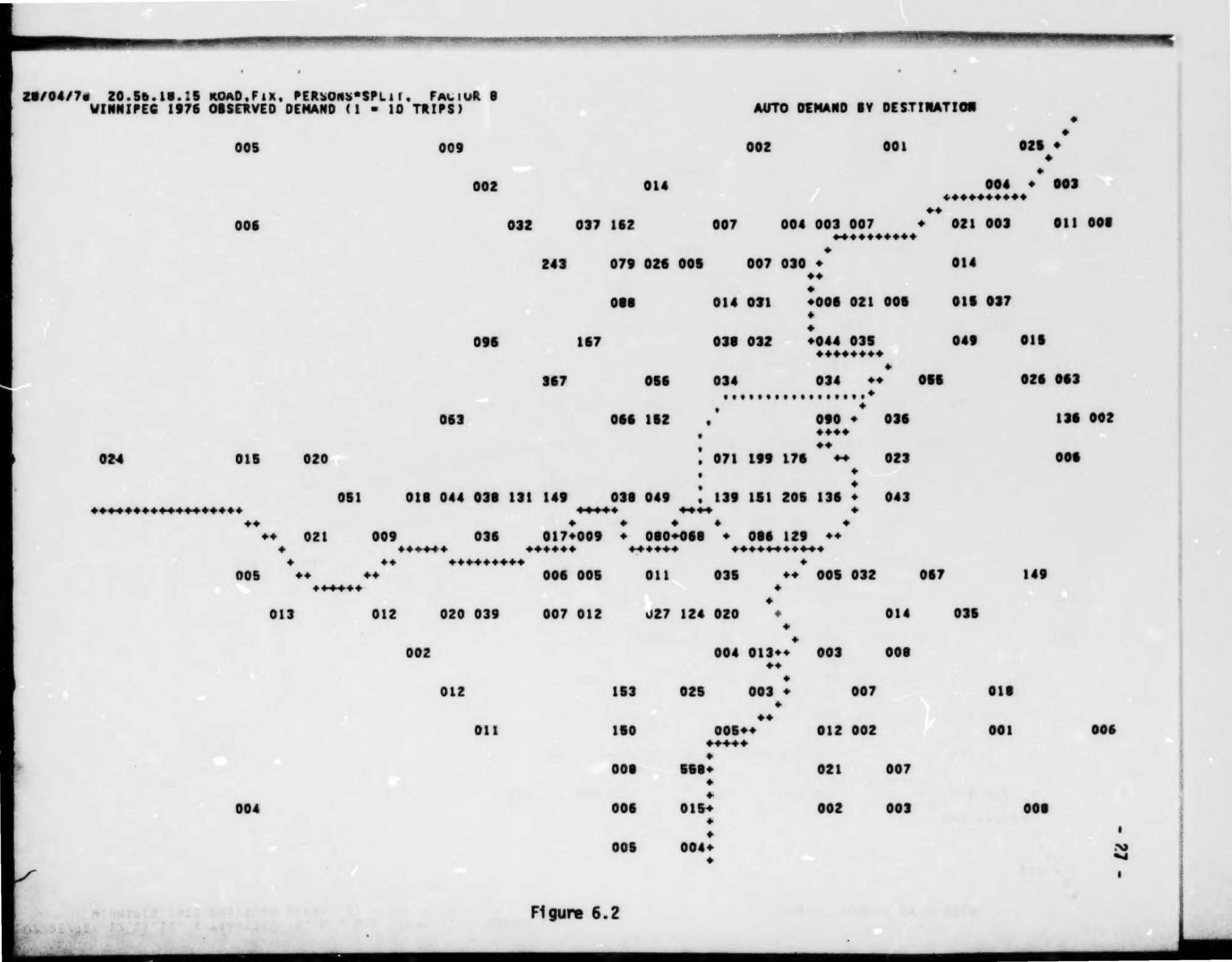

28/04/78 20.56.18.15 ROAD,FIX, PERSONS*SPLIT, FACTOR 8
WINNIPEG 1976 OBSERVED DEMAND (1 = 10 TRIPS)
AUTO DEMAND BY DESTINATION

Figure 6.2

02/05/78 17.01.13. 4 TRANSIT,FIX, NEW O-D (ZONE 59) COMMON L
WINNIPEG 1976 OBSERVED DEMAND (1 = 10 TRIPS)

TRANSIT DEMAND BY ORIGIN

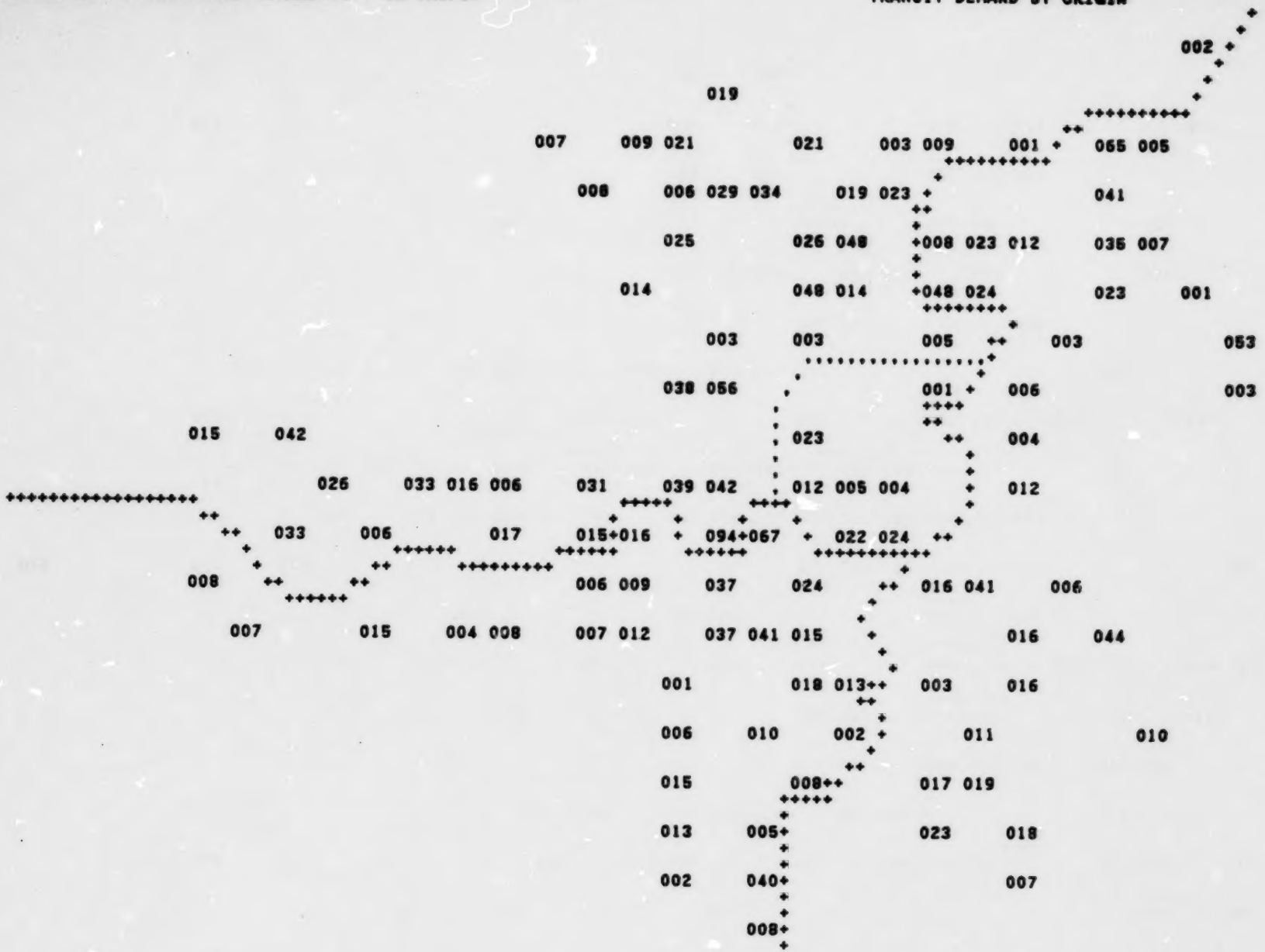


Figure 6.3

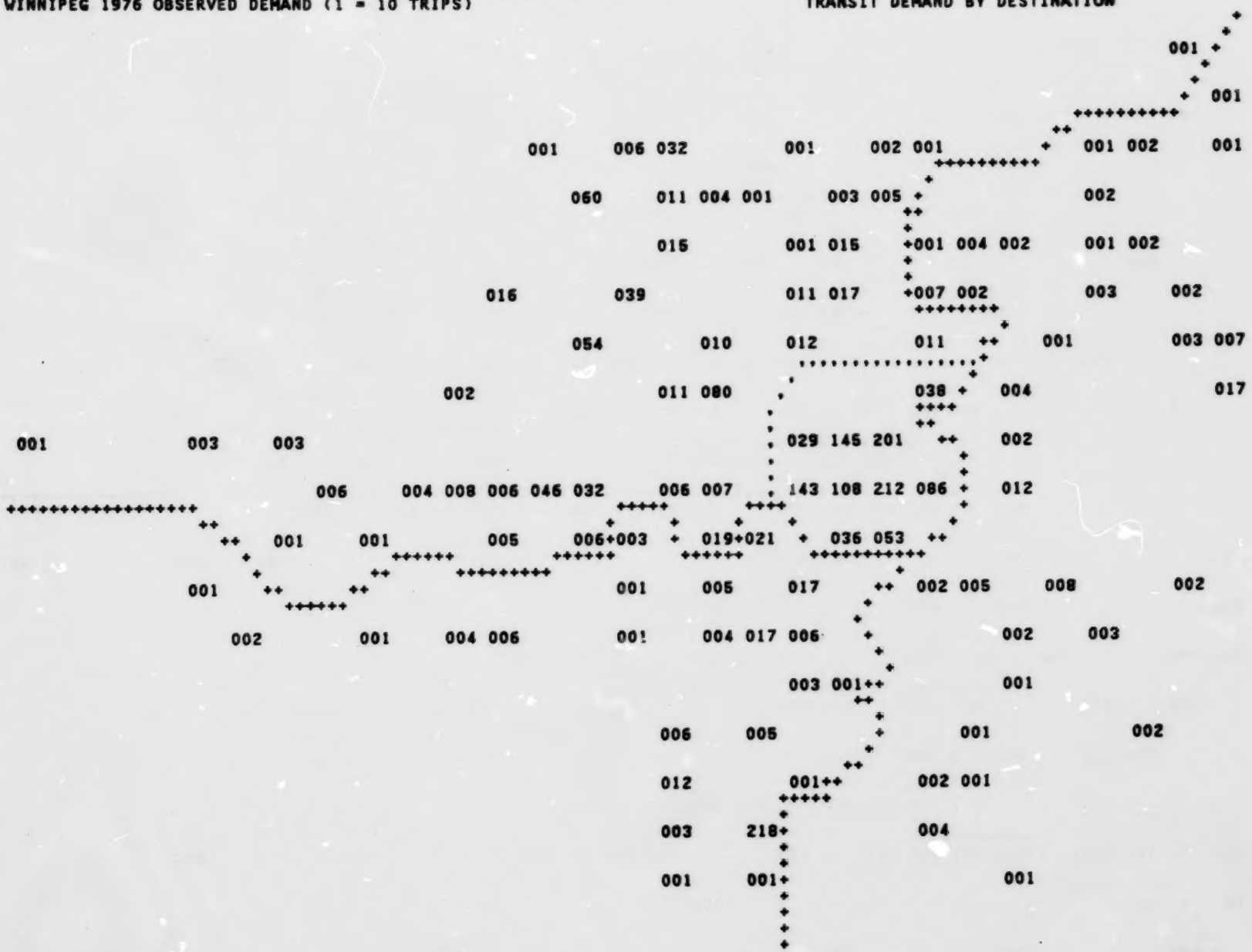

WINNIPEG 1976 OBSERVED DEMAND (1 = 10 TRIPS)
TRANSIT DEMAND BY DESTINATION

Figure 6.4

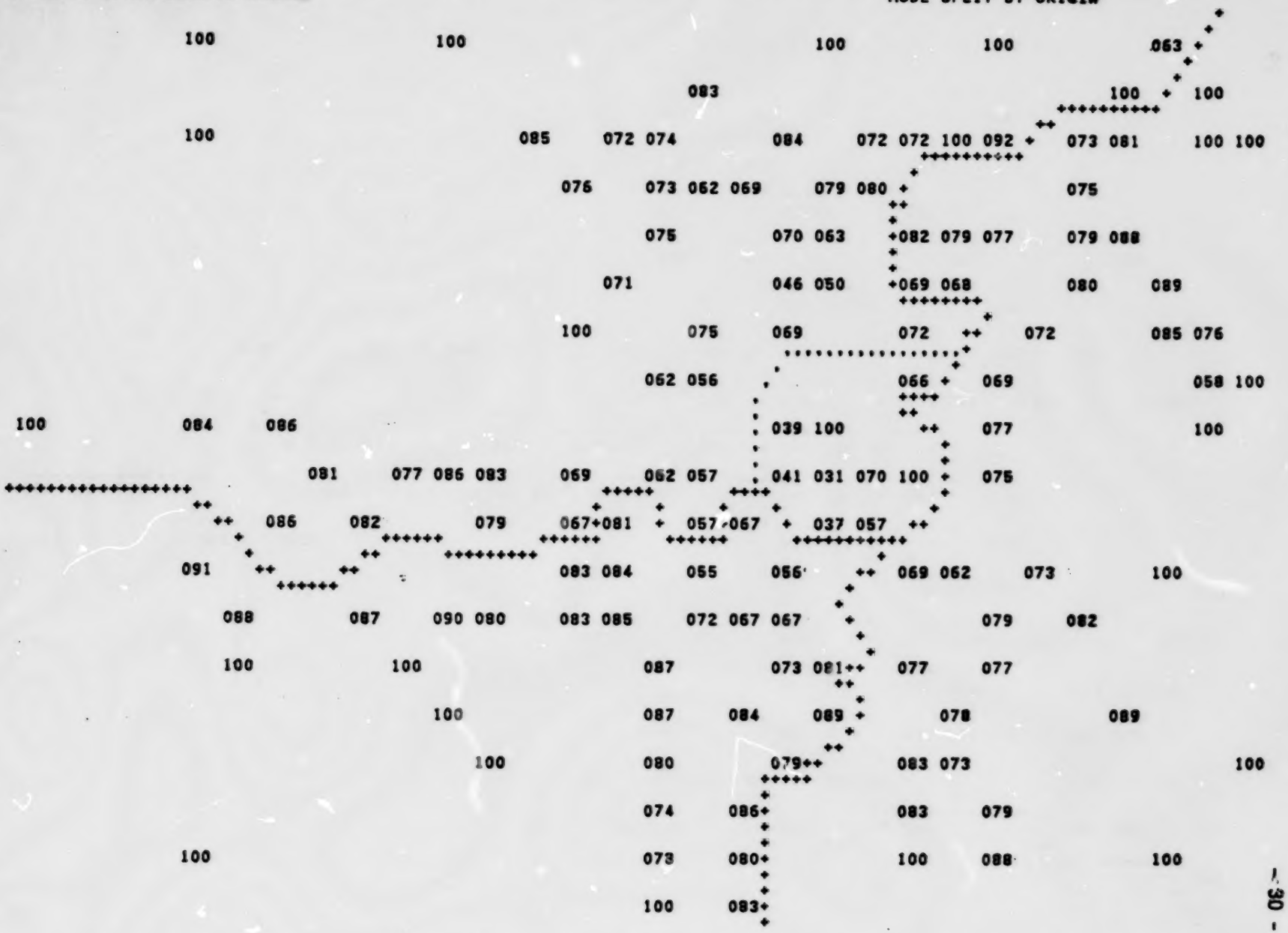


Figure 6.5

02/05/78 17.01.13. 4 TRANSIT,FIX, NEW O-D (ZONE 59) COMMON L
WINNIPEG 1976 OBSERVED DEMAND
28/04/78 20.56.18.15 ROAD,FIX, PERSONS*SPLIT, FACTOR 8
MODE SPLIT BY DESTINATION

Figure 6.6

. road travel times (6)

and by tracing a set of shortest paths on the links that carry flow we obtain the O-D matrix of

. distance by road (7)

Next, the transit O-D matrix was used to calibrate the transit assignment. Other than refinements of the transit network representation, this calibration determines the coefficients of generalized time (or cost in the expression

$$\text{Transit impedance} = \alpha\,(\text{Access Time} + \text{Egress Time} + \text{Wait Time}) + \beta\,(\text{In Vehicle Time}$$

As described earlier the values for α and β, determined in cooperation with the City of Winnipeg, are 3 and 1 respectively. Thus we obtained the O-D matrix of

. transit impedance (8)

and by tracing the shortest paths used we determined the O-D matrix of

. No. of transit transfers (9)

Since our approach is to calibrate a zonal aggregate modal split function, we extracted from the survey data the average car ownership/household/zone, the proportion of new traveling at the peak hour and the proportion of students traveling at the peak hour for each O-D pair.

The other socio-economic variables were obtained by the City of Winnipeg from various sources and transmitted to us. The Statistics Canada 1976 Census served to obtain the average income/household/zone and the O-D survey served to estimate the number of jobs/zone. The parking costs month/zone and the number of parking space/job/zone were evaluated by using 1971 data.

Thus, in all, a file was constructed that consisted of the dependent variable, the modal split, and the independent explanatory variables outlined above. This file contained the records for all O-D pairs thad had more than 60 trips by both modes in the expanded matrix (3) of trips by both modes. The main reason for adopting this procedure is that the modal split for O-D pairs with smaller demand would have far more variability due to the relatively small number of trips in the sample.

The functional form that we chose for the calibration is that of the logistic

function. Although this form achieved recent fame in its use as a disaggregate probabilistic choice function, we use it with aggregate data due to its ease of manipulation and its property of predicting choice values with a smooth ogive type curve. The form that we used is

$$p_{au} = 1 / 1 + \exp\ (k_o + \sum_i k_i\ x_i)$$

where p_{au} is the proportion of trips that occur by car

k_o is a constant and

k_i , i=1,...,m are the coefficients associated with the

x_i , i=1,...,n explanatory variables.

A simple algebraic manipulation results in the form

$$\ell n\ (\frac{1-p_{au}}{p_{au}}) = k_o + \sum_i k_i\ x_i$$

which is used for calibrating k_o , k_i , i=1,...,n by simple linear regression. This method of estimation is often referred to as Berkson-Theil estimation to acknolwedge their early work [2], [19] with aggregate logistic function calibration.

Another functional form that we tried is the so-called 'dogit' proposed recently by Gaudry [9] which adds to the logit form modal constant θ_{au}, θ_{tr} as follows:

$$p_{au} = \frac{1}{1+\theta_{au}+\theta_{tr}}\ (\frac{1}{1+\exp\ (k_o + \sum_i k_i\ x_i)} + \theta_{au})$$

However, in all the trials that we performed, the best values for θ_{au} , θ_{tr}, were always zero, that is the logistic function was satisfactory and neither of the two modes considered had a fixed proportion (θ_{au} or θ_{tr}) of the modal split as an advantage.

The actual calibration test spanned a period of eight months during which several hundred regressions were run, by using also transformations of the explanatory variables. The best modal split model for all the considered

O-D pairs is given in the following table:

Variables	Parameter Value	95% confidence interval	
Constant (k_0)	2.563	1.758	3.369
transit impedance	-0.0122	-0.220	-0.00242
auto time	0.0220	0.00192	0.0422
proportion men	-3.279	-4.117	-2.441
parking cost	0.0745	0.0532	0.0957
car availability	-1.904	-2.726	-1.082
R^2	.60		
R	.77		

Table 6.1 - Model 1

We were not entirely satisfied with this model, in particular since the best fit obtained with a transformation of variables was not much better, as can be seen below:

Variables	Parameter Value	95% confidence interval	
Constant (k_0)	16.566	10.000	-23.131
$(\text{transit impedance})^2$	-0.000758	-.000127	-0.000242
$(\text{auto time})^2$	0.000242	-0.000180	0.000665
$(\text{proportion men})^2$	-2.256654	-3.478	-2.234
parking cost	0.36340	0.276	0.444
ℓn (income)	-1.752	-2.446	-1.058
R^2	.64		
R	.80		

Table 6.2 - Model 2

We proceeded then to subdivide the origins into subgroups by using a criterion related to the error introduced by the modal split function. We reasoned that, errors on individual O-D pairs were unavoidable, however the model should not distort the O-D matrix, that is there should not be too much bias introduced on demand totals by origins and destinations. Thus, we subdivided the origins

into subgroups according to the error introduced by the model on origin totals; thas is, origins which had negative deviations were grouped together and similarly origins with positive errors and origins which had acceptable error formed a second and third subgrouping. Finally we obtained four modal split models as follows.

Variables	Parameter Values			
	Model 3a	Model 3b	Model 3c	Model 3d
Constant	2.352 (1.004 5.708)	1.516 (0.297 2.735)	3.071 (-0.0140 6.156)	2.935 (1.860 4.010)
transit impedance	-0.0133 (-.0532 0.0265)	-0.0101 (-.0221 0.00178)	-0.0315 (-0.0513 -0.0118)	-0.0139 (-0.0408 0.-131)
auto time	0.0334 (-.0503 0.117)	0.0253 (0.000186 0.0504)	0.0733 (0.0343 0.112)	0.0323 (-0.0302 0.0949)
proportion men	-2.799 (-.5.646 0.0491)	-3.719 (-4.827 -2.611)	-3.101 (-5.043 -1.159)	-2.499 (-4.020 -0.978)
parking cost	.0959 (0.0225 0.169)	.0968 (0.0694 0.124)	.0471 (0.00471 0.0895)	.0332 (-0.0124 0.0787)
car availability	-3.023 (-6.359 0.312)	-1.232 (-2.394 -0.0698)	-1.502 (-4.686 1.682)	-1.844 (-3.139 -0.548)
R^2	.72	.67	.78	.64
R	.85	.82	.88	.80
No. of O/D pairs	26	135	36	45

The numbers in parentheses are the 95% confidence interval for the values of the parameters.

Table 6.3

7. BASE YEAR CALIBRATION - BI-MODAL MODEL

The execution of a bi-modal assignment in EMME requires the simultaneous use of the vehicle assignment, the transit assignment and the modal split function. As described earlier in this report, each of these model is calibrated independently and then they are used jointly in the computations. Since each of these models introduces a certain error by its calibration it is certain that there will be some differences between the observed values and the output of the bi-modal computations for the base year. Fortunately, these differences are not large and are well within the variances which are acceptable in calibration of transportation models.

The staff of the City of Winnipeg asked that we apply the modal split function to all the origin-destination pairs, even though we had calibrated the model by using only origin-destination pairs that had more than 60 trips in the expanded total trip matrix. This became necessary since only about 28% of the total trips were represented by that sample. Thus, we applied, to all origins that were not represented in the calibration data, the initial modal split model (model 1). For all other origins, we applied the corresponding modal split models to all the relevant destinations. The results were surprisingly good. Only 307 trips, or .5% of the total number of trips, are the difference between the observed total number of trips by auto and the differences that result on trip ends, that is origin and destination totals, are mostly of the order of up to 8%.

Figure 7.1 illustrates the auto demand by origin for the base year. All origins that generate more than 500 trips during the peak hour are hidhlighted by the corresponding figure being enclosed in a rectangle. Figure 7.2 shows the relative demand difference as a fraction of the demand by origin. Except for origin zones 46 (0.22), 81 (0.13) and 80 (0.17) all other differences are acceptable and do not exceed .10. Figures 7.3 and 7.4 show respectively the observed modal split by origin, with the rectangles again highlighting origins that have more than 500 trips, and the modal split predicted by the bi-modal for the base year. Again, except for origins 46, 81 and 80 the calibration provides a very good fit to the observed modal split.

A similar analysis was carried out by destination. Figure 7.5 shows the

observed demand by destination zone and Figure 7.6 the relative difference in demand by destination. The largest differences, for destinations of more than 500 trips are .13 for zone 147, and .11 for zone 47, while all other differences for the large zones are less than .10. Figures 7.7 and 7.8 give the observed and predicted modal split by destination.

We judged these demand differences acceptable in view of the general consideration that the 'true' demand varies daily and differences of the order of 10% between various days of the week are accepted to be common place. Further, these differences were not sufficiently high to materially change the orders of magnitude of the link flows on the important arteries.

The computing times and the corresponding costs on the CDC Cyber 176 of the Université de Montréal for the base year bi-modal run are as follows:

. Generate transit network	3.66
. Calculate bus frequency	1.23
. Calculate transit impedance	1110.55
. Initialize road traffic demand	3.44
. Perform road traffic assignment	2509.44
. Modify transit link times	67.61
. Calculate fixed transit demand	1.77
. Calculate demand function (transit)	0.00
. Perform transit assignment	423.91
. Modify transit capacity	0.00

Central Processor	$189.20
Input-Output	22.80
Fast Memory	560.40
	$772.40

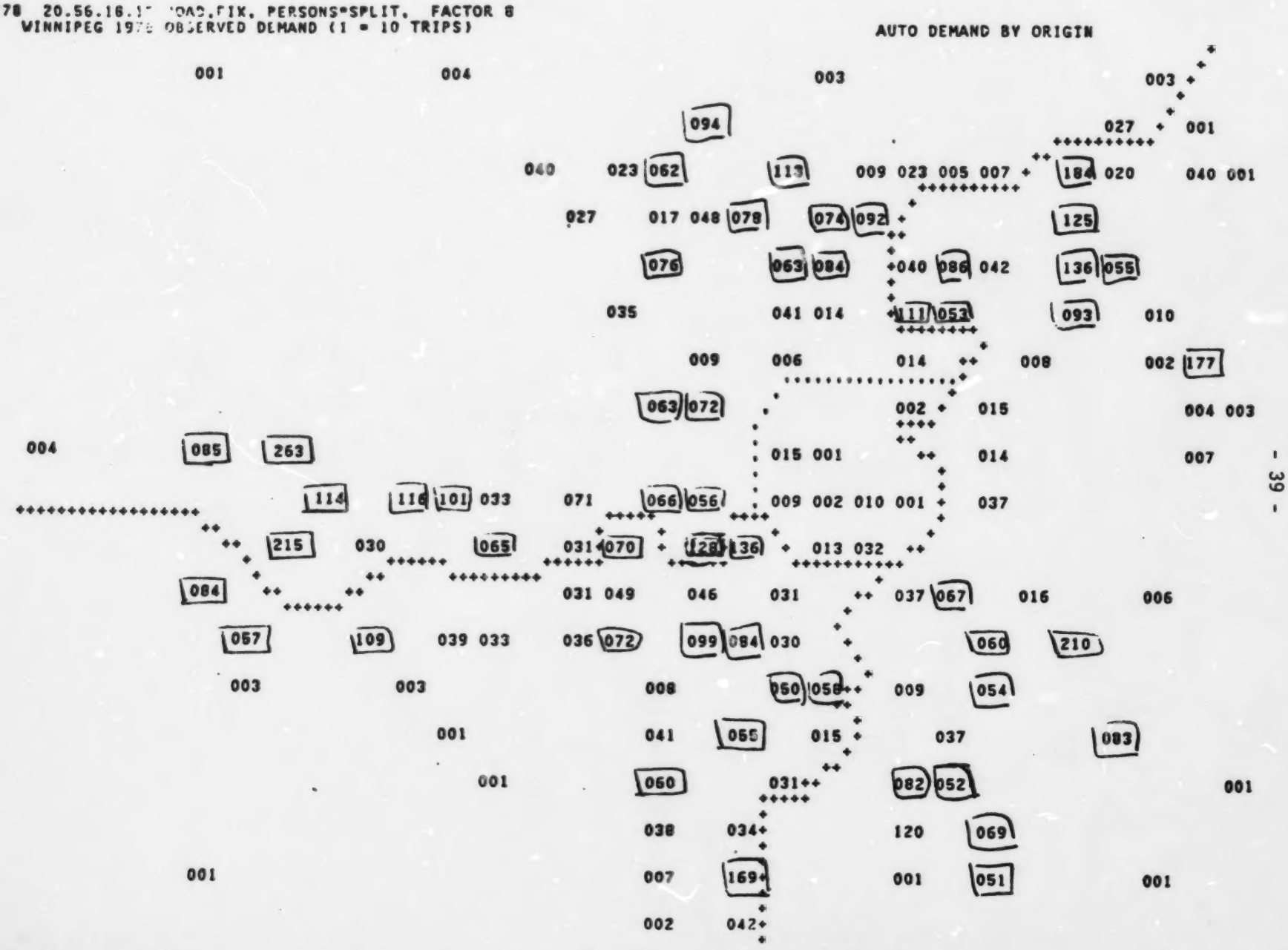


Figure 7.1 ☐ Origin demand larger than 500 trips

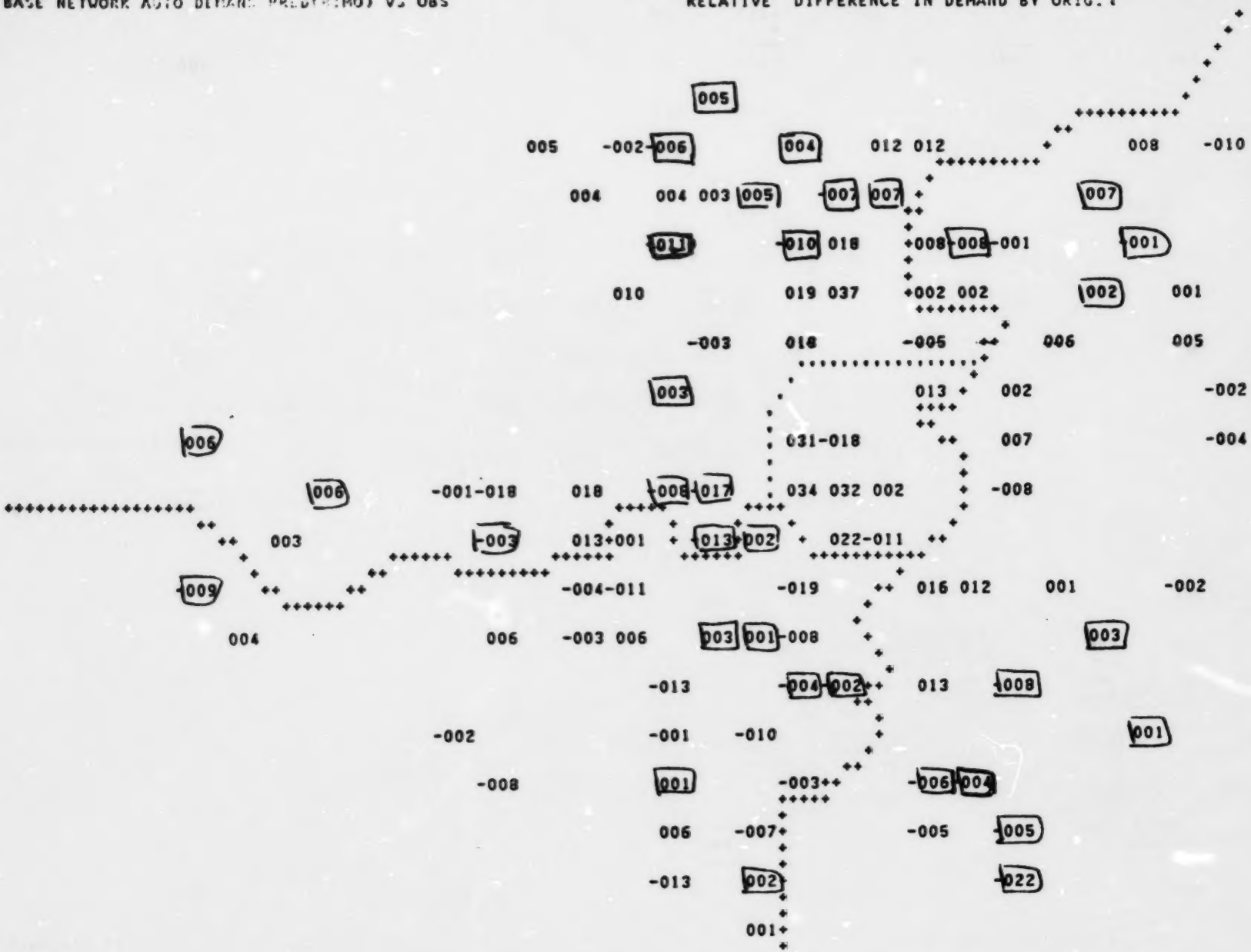


Figure 7.2 ☐ Relative difference in demand for origin larger than 500 trips

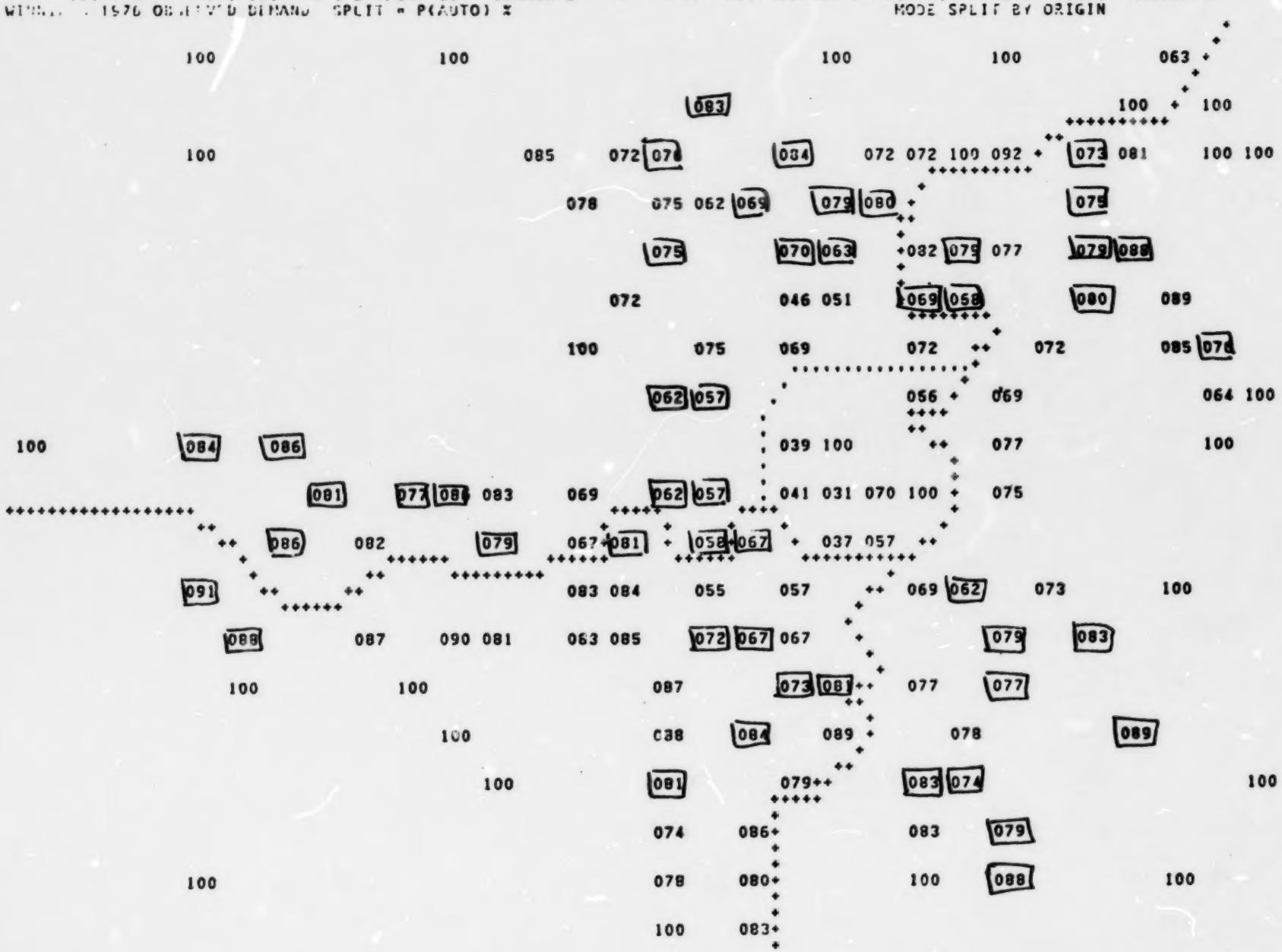


Figure 7.3 ☐ Origin demand larger than 500 trips

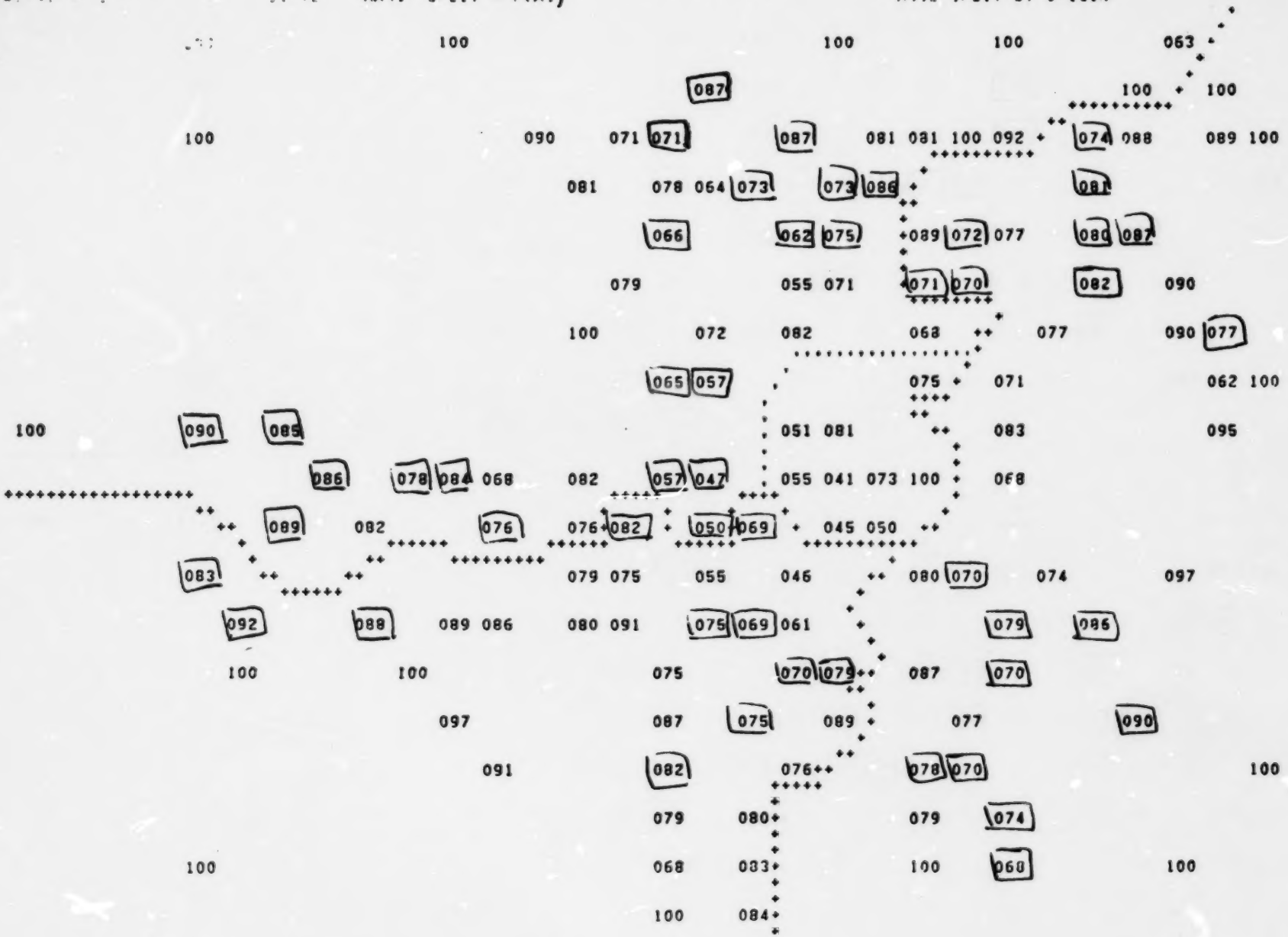


Figure 7.4 ☐ Origin demand larger than 500 trips

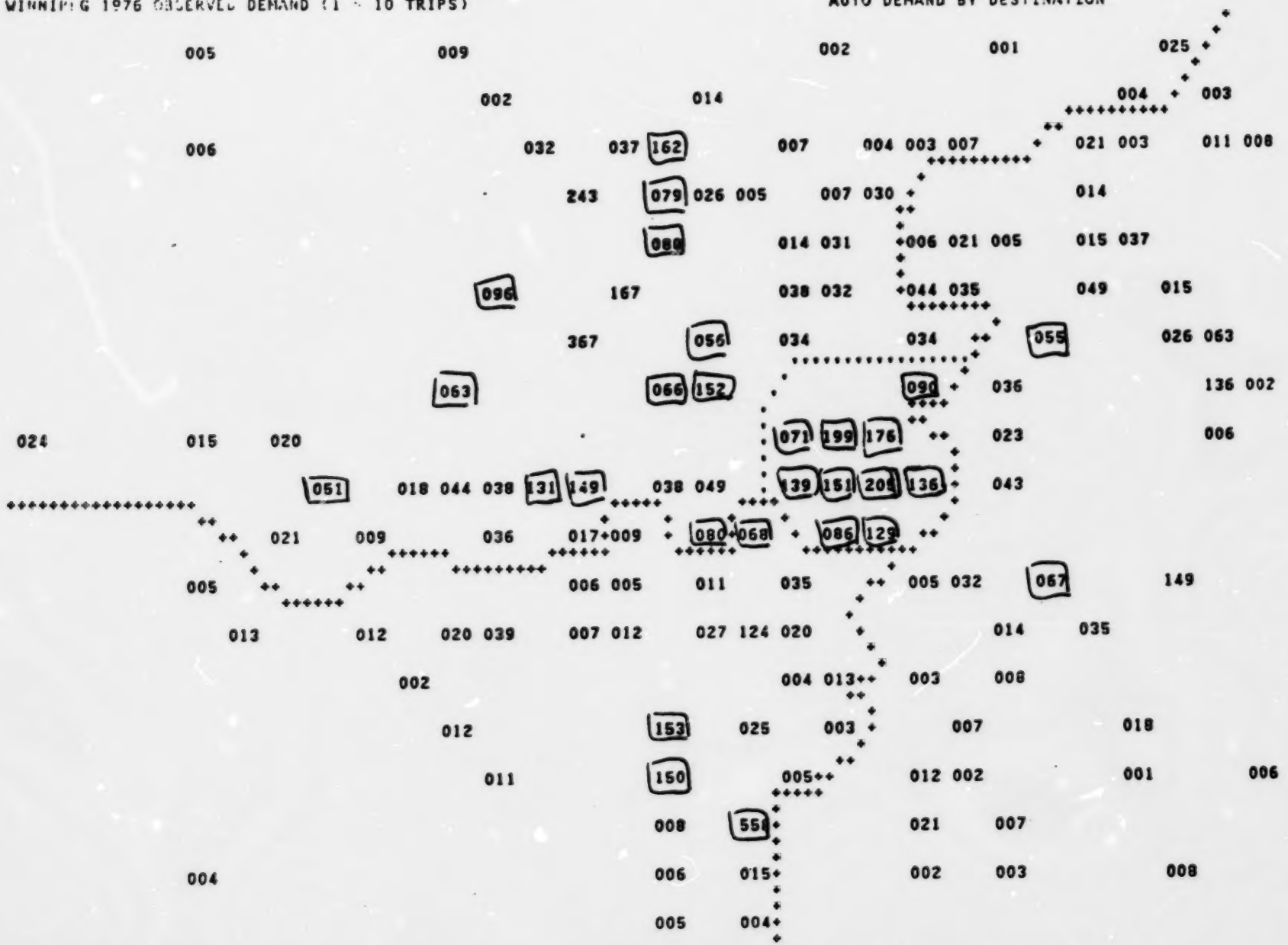


Figure 7.5 ☐ Destination demand larger than 500 trips

17/06/78 03.10.40. 3 1976 BIMODAL (5 ZONE GROUPS)
BASE NETWORK AUTO DEMAND PRED(BIMO) VS OBS

X 28/04/78 20.56.18.15 ROAD.FIX. PERSONS*SPLIT. FACTOR 8
RELATIVE DIFFERENCE IN DEMAND BY DESTINATION

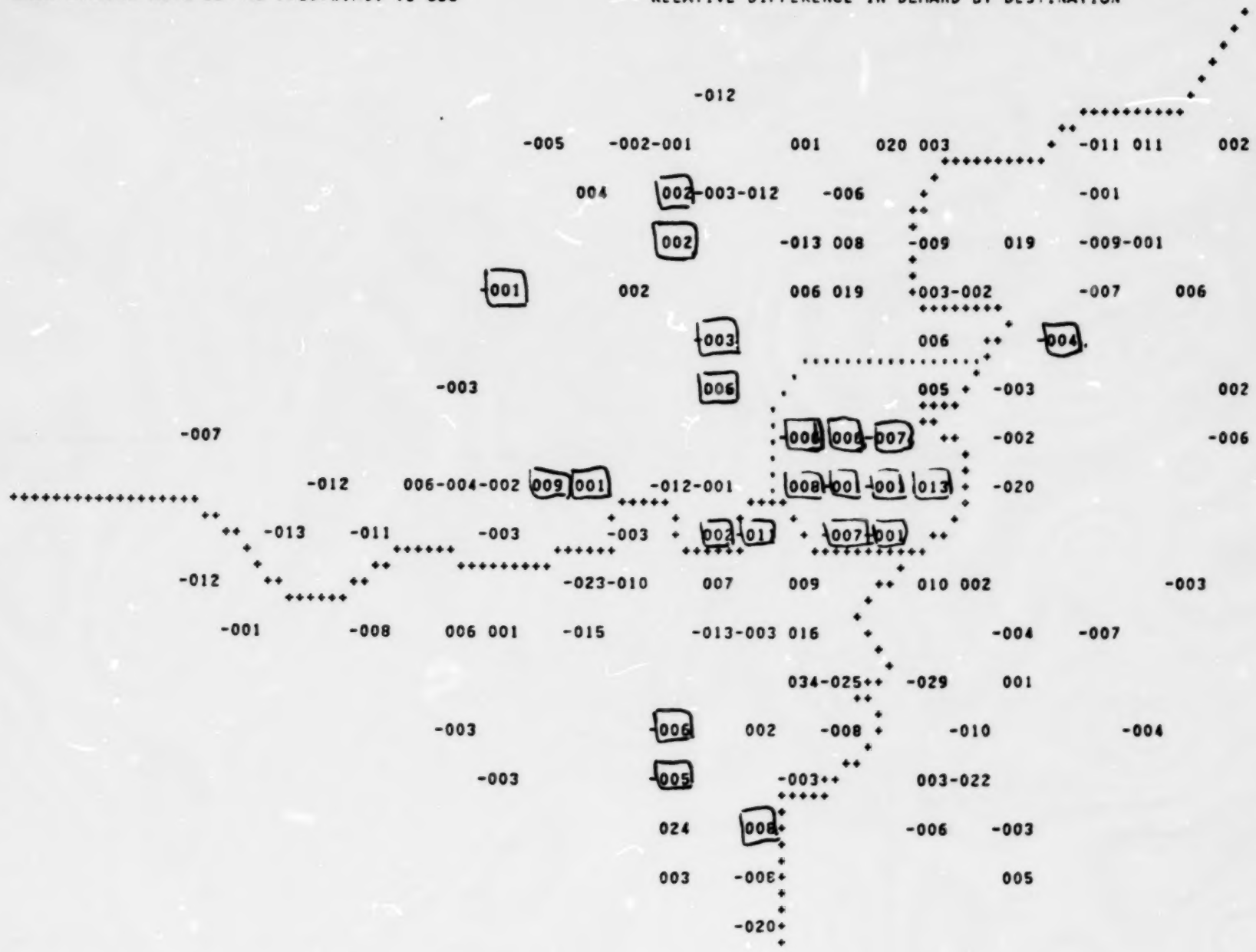


Figure 7.6 ▭ Relative difference in demand for origins larger than 500 trips

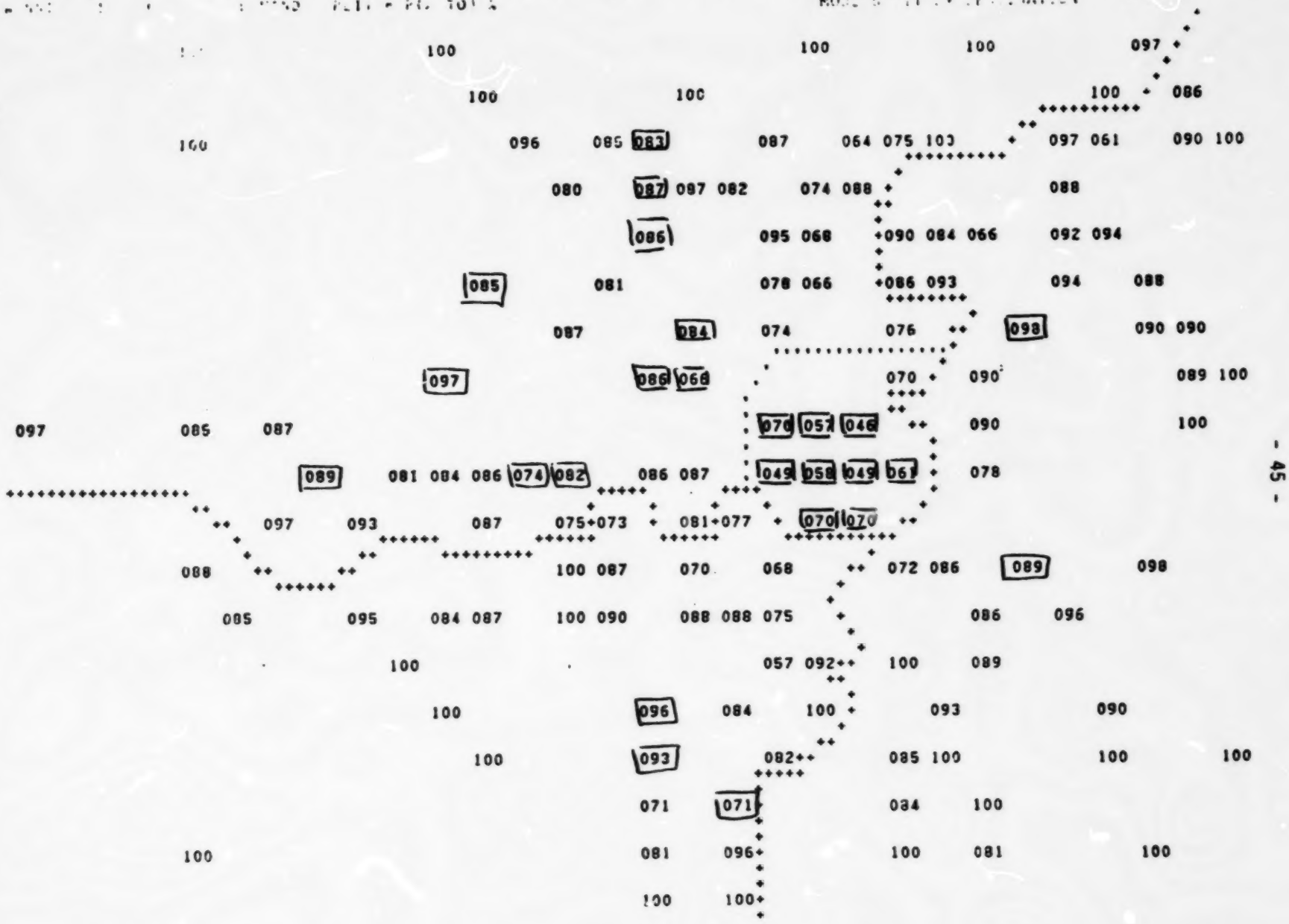


Figure 7.7 ☐ Destination demand larger than 500 trips

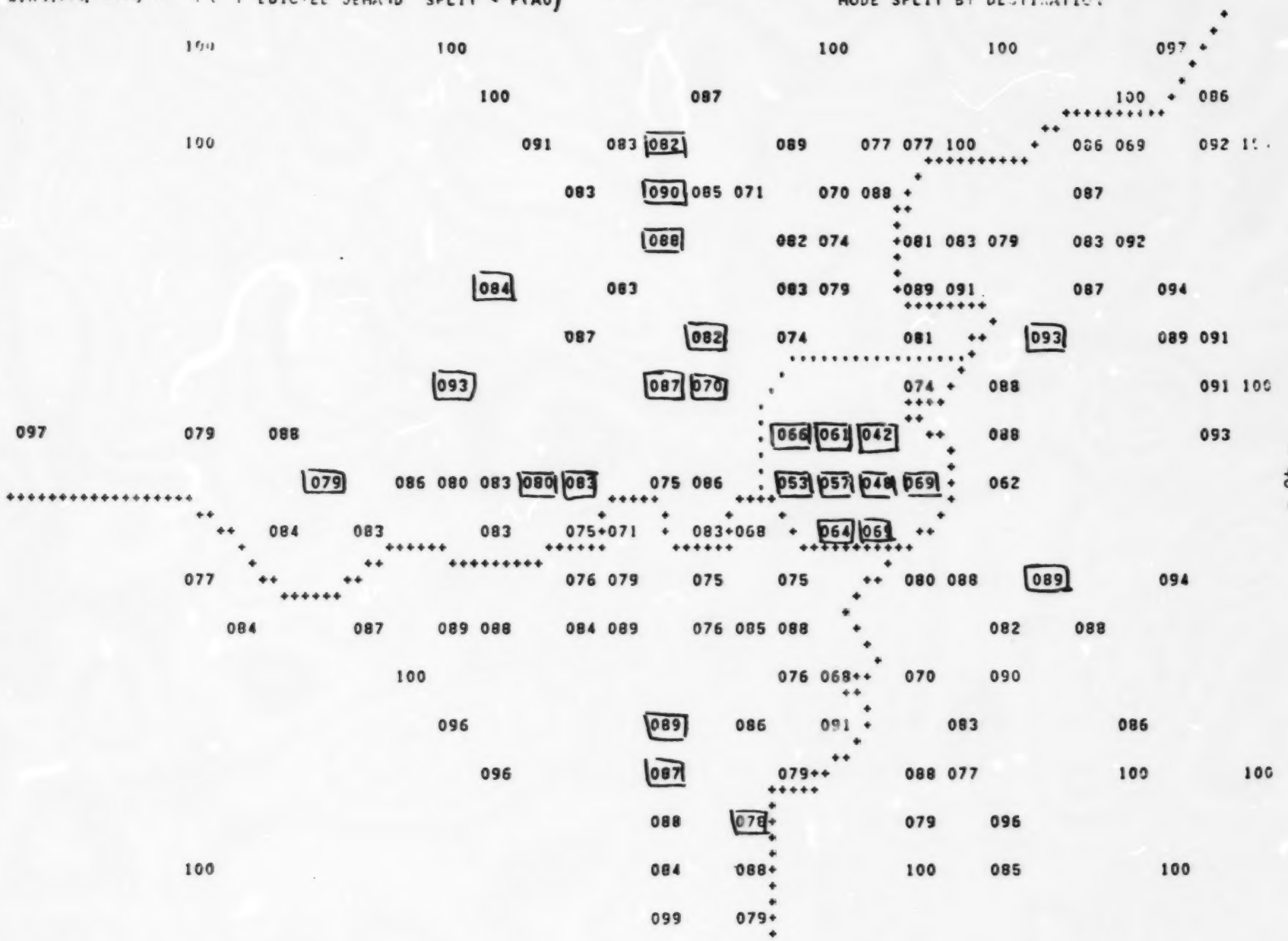


Figure 7.8 ▭ Destination demand larger than 500 trips

8. IMPACT OF THE BUSWAY AND ST.VITAL BRIDGE SCENARIOS

There are several ways in which EMME may be used to simulate (predict) the impact of contemplated improvement scenarios. One may use the single mode assignment modules and thus simulate the impact of the scenario without changing the modal shares of the demand. This may be appropriate for some situations where only marginal improvements are made and the only interest is to anticipate the changes in route choice that result due to the modifications. However most of the current transportation planning methods in use have this capability. The other way to use EMME is to simulate the impact of each scenario with a full bi-modal run, which would predict the anticipated changes in modal share of demand as well. This capability is so far unique to EMME and in the description that follows we will discuss mainly the impacts of the contemplated scenarios predicted by full bi-modal runs of EMME.

We were provided by the City of Winnipeg with a road improvement scenario and a transit improvement scenario.

The road improvement scenario consists of the addition of a bridge and access roads across the Red River joining the Fort Garry and St.Vital community areas. The bridge has four lanes between the Pembina Highway and St.Anne's Road and two lanes from there until it meets the Lagimaudiere Boulevard. The project involves as well an extension of Dakota Street to the site of a new shopping centre. This scenario involved the addition of 19 nodes and 96 links to the road network.

The transit improvement scenario is the Southwest Transit Corridor. In May 1975, the City of Winnipeg, in co-operation with the Province of Manitoba and the Federal Government, initiated the Southwest Transit Corridor Study. The objective of the study was to examine the feasibility of implementing a new rapid transit system on its own right of way between the downtown area and the University of Manitoba. The study carried out by De Leuw-Dillon in association with the Lombard North Group, recommended a busway route along a two lane roadway extending for 6.75 miles between Bison Drive in Fort Garry and Pioneer Avenue in the downtown area. The operation of buses in that region of the town would be reorganized to take advantage of the busway: the buses

would circulate through the local neighbourhoods, the University and the downtown area using the local street system; then they would run via the busway to provide fast service between areas of the corridor and the downtown. More specifically 3 lines are affected: lines 13 and 41 will be using the busway and every third bus of line 40 will be using the busway as well. On the transit network this scenario resulted in the removal of two lines (13 and 41), modifying the frequency of one line (40) and the addition of three new lines (13, 41 and 40 on busway).

The impact of the South-West corridor Busway, as simulated by EMME, is of significant proportion. Figures 8.1 and 8.2 show the mean trip time in minutes by origin and the predicted difference in the mean time as a result of the busway. As can be easily seen by reference to Figure 8.2, nearly all the origin zones benefit from the busway, since most origin generate trips toward the University of Manitoba and the origin zones in the south-west quadrant of the city benefit as well from the busway. Figures 8.3 and 8.4 show the mean trip time in minutes by destination and the predicted difference in the mean time as a result of the busway. It is easy to see that the impacts of transit travel time by destination are concentrated in the CBD arcs and the south-west corridor.

The transit ridership and the lines that use the busway is increased from 3,544 to 6,062. The difference of 2,518 passengers consists of 717 passengers attracted by auto to transit and 1,301 passengers that change their route to use bus lines that run on the busway. Table 8.1 indicates the maximal ridership and total number of passengers using the lines 41, 40 and 13 in the base year simulation and Table 8.2 indicates the same statistics for the simulation of the busway scenario.

The global statistics are given in Table 8.3.

Line No.	Maximal ridership		Total No. of pass. using the line
	Northbound	Southbound	
41	411	201	705
13	115	49	286
40	695	1,411	2,553
			3,544 Total

Table 8.1

(variable demand)

Line No.	Maximal ridership		Total No. of pass. using the line
	Northbound	Southbound	
441	725	715	1,880
413	283	111	632
440	1,179	1,570	3,345
40	73	112	205
			6,062 Total

Table 8.2

	Base year	Busway Scenario
Passenger minutes	573 809.1	520 976.7
Average transit trip in min.	41.53	37.86
Average in-vehicle time	28.47	24.96
Average waiting time	4.45	4.49
Average access & egress time	8.62	8.41
Average number of transfers	.68	.75
Total number of transit-passengers	20 187.00	20 904.00
Global modal split	76.13 (auto)	72.53 (auto)

Table 8.3

MEAN TRIP TIME (MINUTES) BY ORIGIN

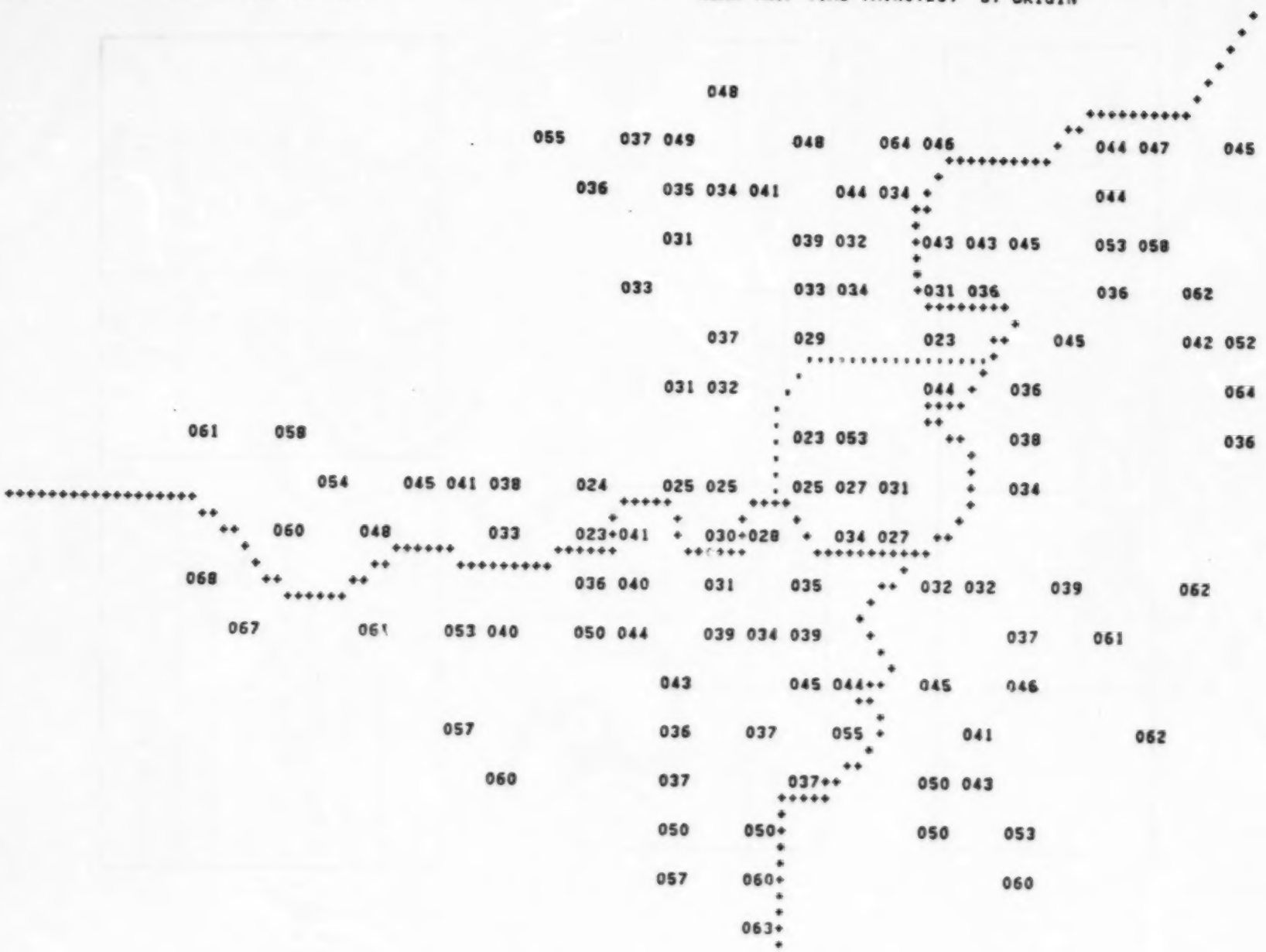


Figure 8.1

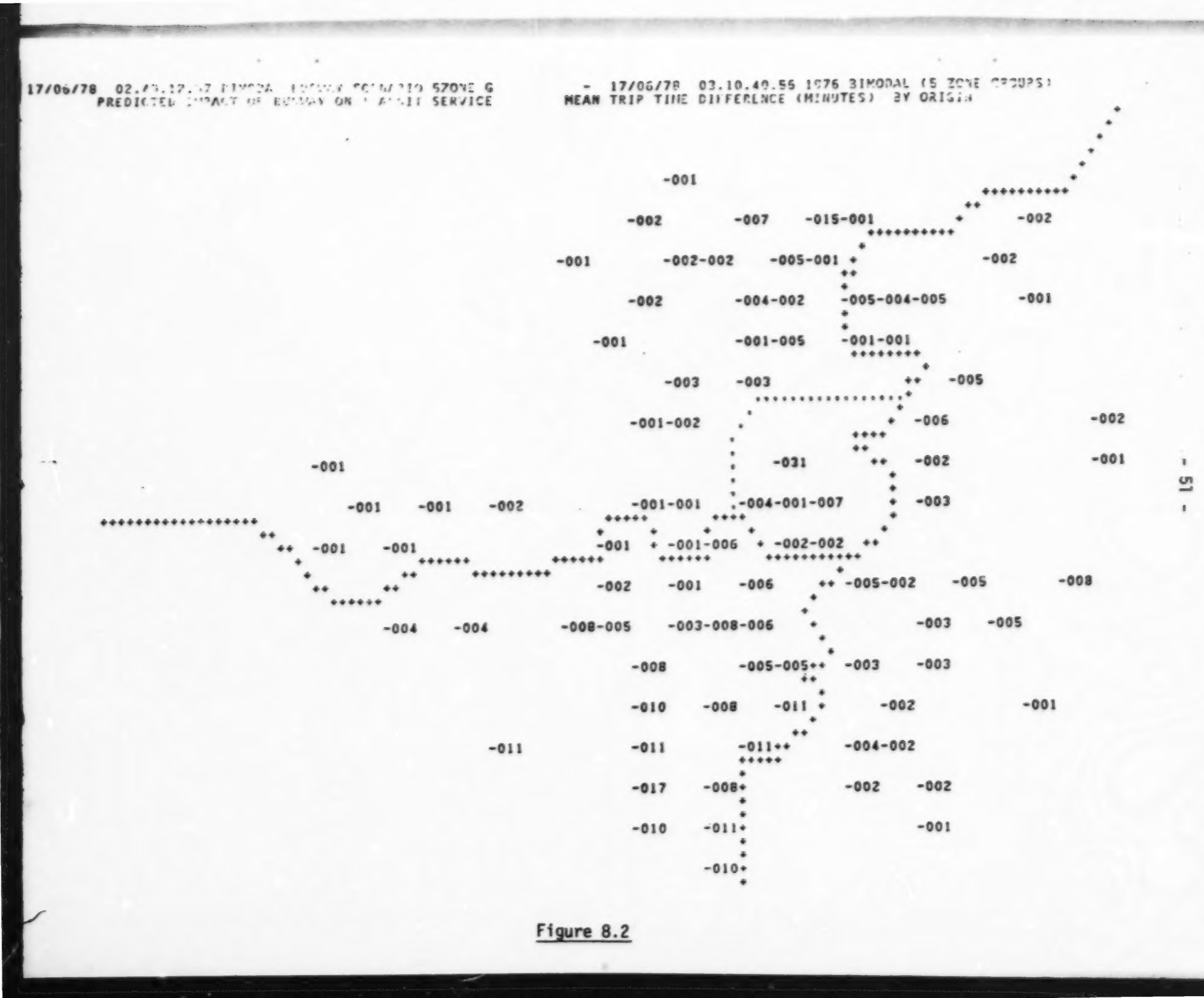

17/06/78 02.43.17.37 BIMODA
PREDICTED IMPACT OF BUSWAY ON
SERVICE
ZONE G
17/06/78 03.10.40.55 1976 BIMODAL (5 ZONE GROUPS)
MEAN TRIP TIME DIFFERENCE (MINUTES) BY ORIGIN
-001
-002 -007 -015-001 -002
-001 -002-002 -005-001 -002
-002 -004-002 -005-004-005 -001
-001 -001-005 -001-001
-003 -003 -005
-001-002 -006 -002
-001 -031 -002 -001
-001 -001 -002 -001-001 -004-001-007 -003
-001 -001 -001 -001-006 -002-002
-002 -001 -006 -005-002 -005 -008
-004 -004 -008-005 -003-008-006 -003 -005
-008 -005-005 -003 -003
-010 -008 -011 -002 -001
-011 -011 -011 -004-002
-017 -008 -002 -002
-010 -011 -001
-010

Figure 8.2

048
058 046 040 046 050 048 036 046 051
056 032 035 052 046 037 040
043 037 036 033 034 032 049 055
059 038 041 030 041 036 039 067
046 031 028 037 047 034 064
041 043 037 030 041 055
052 041 033 033 035 040 083
042 043 040 037 041 041 035 041 037 038 035 034 041
047 043 036 037 038 039 037 039 038
065 054 033 036 033 031 041 052 056
064 045 050 050 050 058 037 036 041 034 048
036 036 041 035
064 040 047 042 040 057
056 042 047 037 025
046 060 043 062
058 060 040
083

Figure 8.3

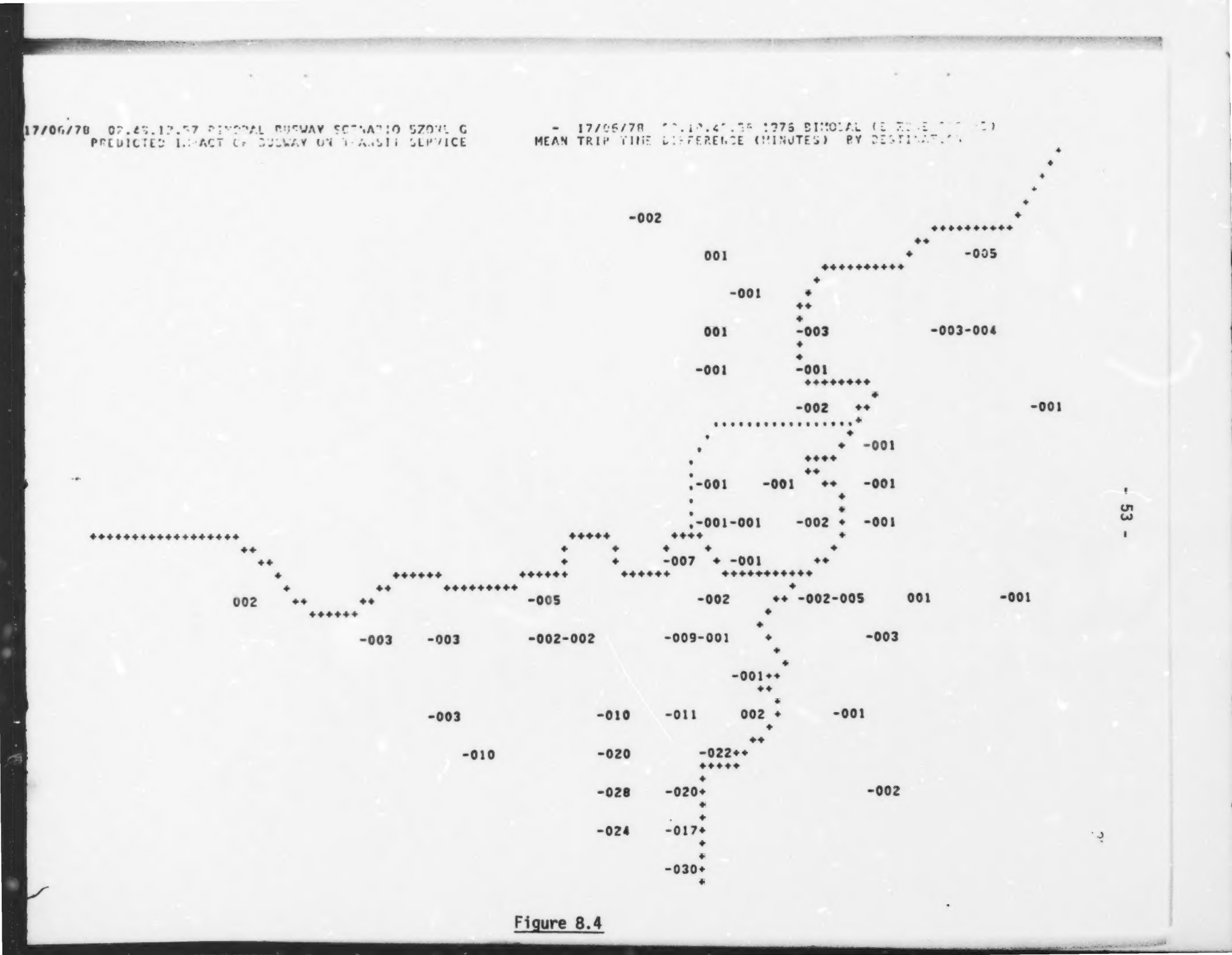

17/06/78 02.45.12.57 REMOVAL RUNWAY SCENARIO SZONE G
PREDICTED IMPACT OF RUNWAY ON TRANSIT SERVICE
17/06/78 MEAN TRIP TIME DIFFERENCE (MINUTES) BY DESTINATION
-002
001
-005
-001
001
-003
-003-004
-001
-001
-002
-001
-001
-001
-001
-001
-001-001
-002
-001
-007
-001
002
-005
-002
-002-005
001
-001
-003
-003
-002-002
-009-001
-003
-001
-003
-010
-011
002
-001
-010
-020
-022
-028
-020
-002
-024
-017
-030

Figure 8.4

The increase in transit demand by origin and destination may be seen in Figures 8.5 - 8.8. Figure 8.5 shows the transit demand by origin and Figure 8.6 shows the difference in demand by origin, with all differences larger than 10% enclosed in a rectangle. Similarly, Figures 8.7 and 8.8 show the transit demand by destination and the predicted differences in demand by destination.

Finally, we show in Figure 8.9 the profile of transit ridership in the northbound and southbound directions on the busway for the transit lines that use it. The maximum predicted ridership points are 2189 and 2374 respectively.

The computer time required for this simulation and the corresponding cost on the CDC Cyber 174 of the Université de Montréal are given below.

Generate transit network	4.14
Calculate bus frequency	1.22
Calculate transit impedance	1206.79
Initialize road traffic demand	3.73
Perform road traffic assignment	2580.66
Modify transit link times	67.66
Calculate fixed transit demand	1.80
Calculate demand function (transit)	0.00
Perform transit assignment	465.52
Modify transit capacity	0.00

Central processor	$198.80
Input - output	24.00
Fast memory	584.80
Total	$807.70

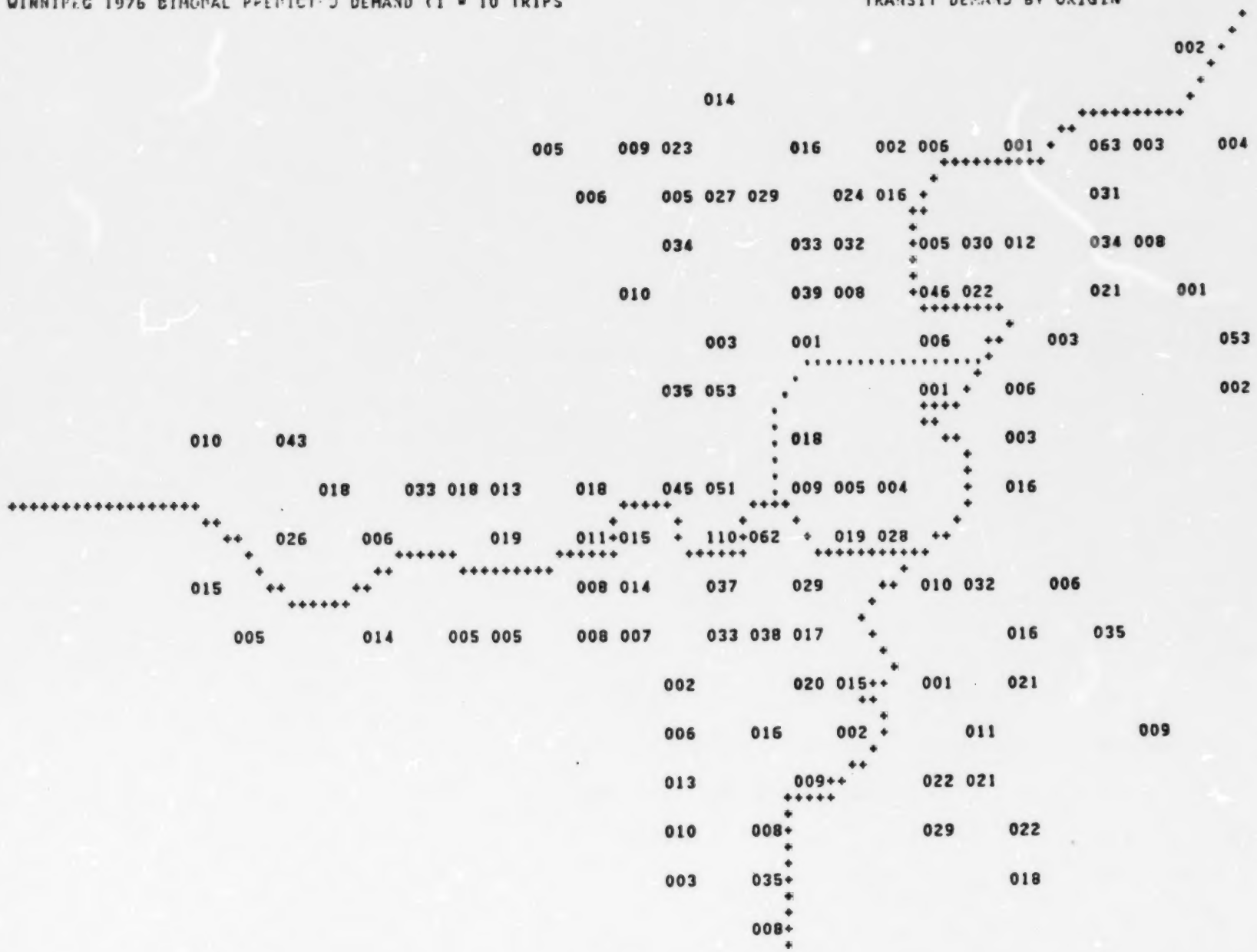

7/06/78 03.10.49. 1 1976 BIMODAL (5 ZONE GROUPS)
WINNIPEG 1976 BIMODAL PREDICTED DEMAND (1 = 10 TRIPS
TRANSIT DEMAND BY ORIGIN

Figure 8.5

17/06/78 02.49.12. 1 BIMODAL BUSWAY SCENARIO SZONE G - 17/05/78 03.10.40. 1 1976 BIMODAL (5 ZONE GROUPS)
BUSWAY: PREDICTED EFFECT ON TRANSIT DEMAND DIFFERENCE IN DEMAND BY ORIGIN

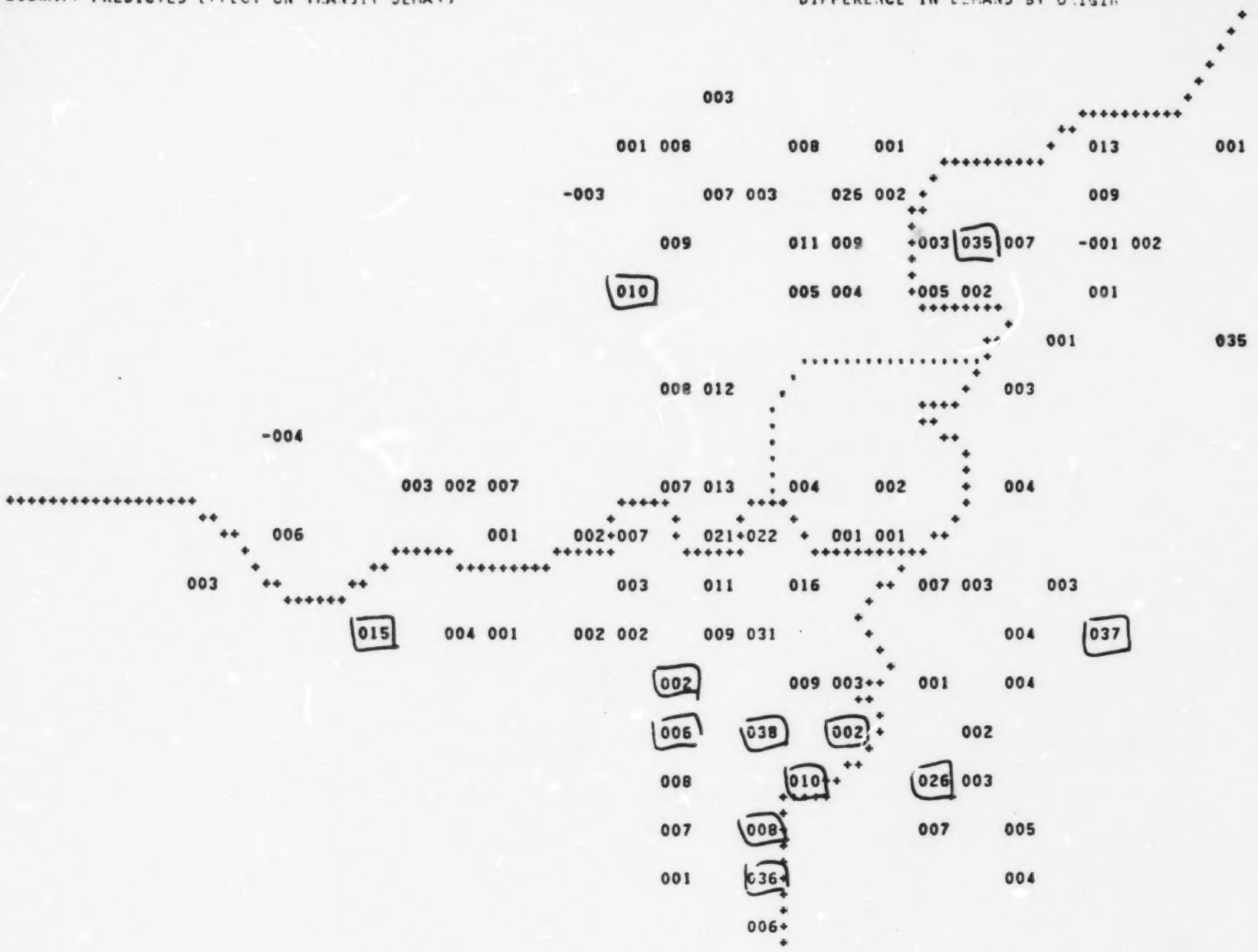


Figure 8.6 - ☐ more than 10% of observed demand - base year.

WINNIPEG 1976 BIMODAL PREDICTED DEMAND (1 = 10 TRIPS

TRANSIT DEMAND BY DESTINATION

Figure 8.7

Figure 8.8 - ▭ Relative difference of more than 10%

Stage no. / Line no.	2804	2135	403	2012	4000	2013	4001	2813	2017	4002	2018	4003	355	2063	869	868
4410	54	54	54	67	133	133	268	388	502	663	972	1098	1179	1146	934	
4401						325	473	500	543	605	654	648	525	682	577	
413									99	160	207	254	285	274	209	
TOTAL	54	54	54	67	133	660	741	888	1144	1428	1833	2060	2189	2102	1710	

NORTHBOUND

Stage no. / Line no.	868	869	2013	355	4003	2018	4002	2017	983	4001	2013	4000	2802	413	2133	2134
4410	1720	1456	1256	1496	1455	1570	1513	1566	1503	1332	1332	1325	1317	1317	1317	
4401	996	512	552	678	660	713	692	715	689	617						
413	76	79	89	41	70	91	68									
TOTAL	1691	1747	1901	2215	2185	2374	2363	2281	2192	1949	1332	1325	1317	1317	1317	

SOUTHBOUND

Figure 8.9 Load on transit lines in the busway

The impact of the Fort-Garry - St.Vital Bridge, as simulated by EMME, is localized to the Fort Garry and St.Vital community areas. Figures 8.10 and 8.11 show the mean trip time by auto by origin and the corresponding mean trip time difference by origin. It is clear that most of the origin zones that benefit are those to the east of the bridge. Similarly, Figures 8.12 and 8.13 show the mean trip time difference by destination and the corresponding mean trip time difference by destination. Again, it is easy to see that most of the destination that benefit from the bridge are to the west of it.

The global statistics merely confirm the localized spatial impacts of this scenario. They are given in Table 8.4 below:

	Base network	Fort Garry - St.Vital bridge
Vehicle hours	20,438.63	19,914.34
Vehicle miles	379,679.73	375,938.20
Average speed mph	18.58	18.88
Global modal split	76.13 (auto)	76.63 (auto)

Table 8.4

There are 185 trips that are predicted to change from transit to auto, which represent .5% change in the modal split. There is a 2.52% reduction in the total vehicle hours and a 1% reduction in total vehicle miles.

The most significant impact is the reduction of the hourly volume on the perimeter bridge, link (325-423) from 1109 to 68. These trips will be using the new bridge, which has a predicted hourly volume of 1987.

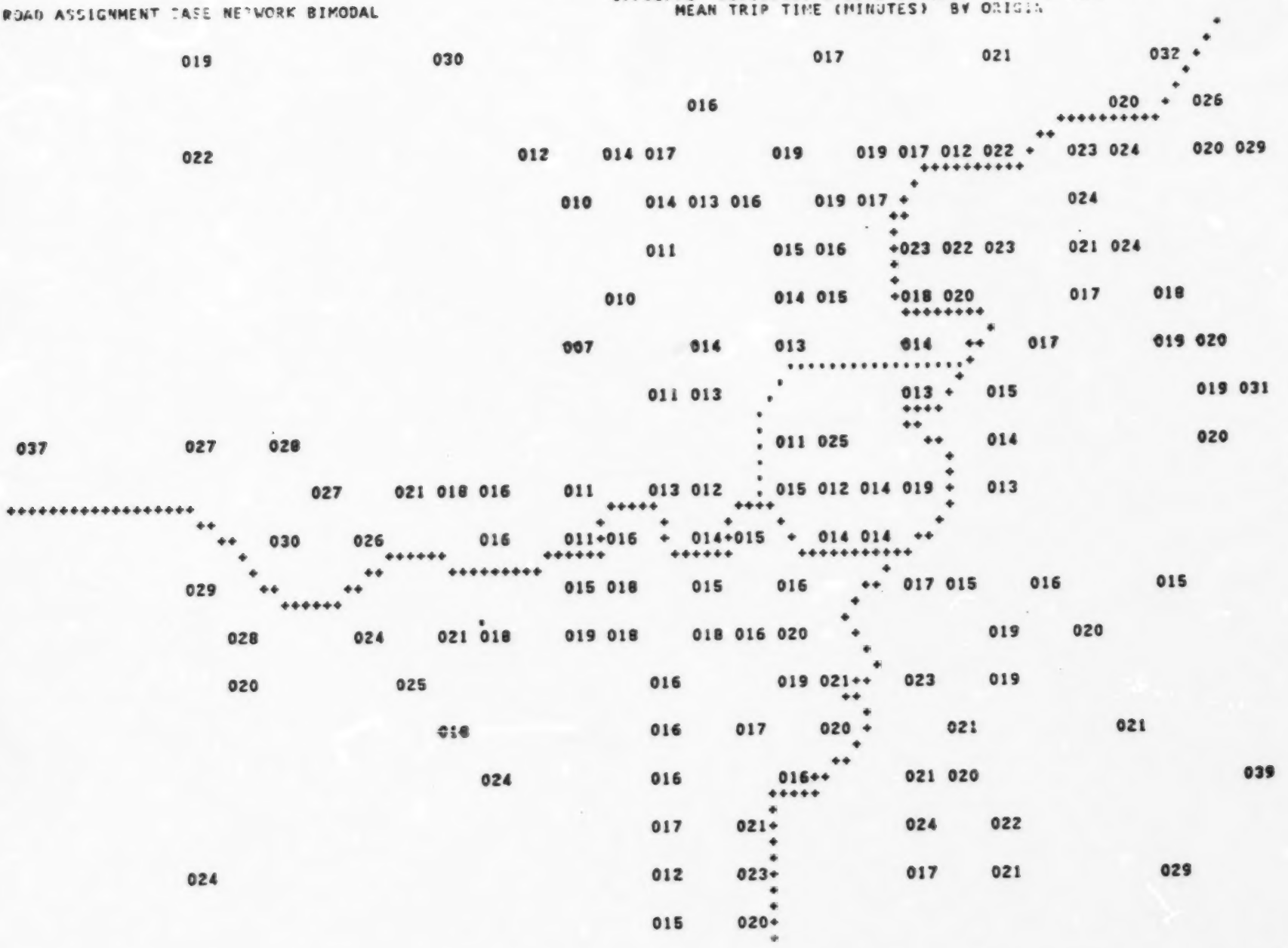

ROAD ASSIGNMENT CASE NETWORK BIMODAL
17/06/78 03.13.40. 3 1976 BIMODAL (5 ZONE PRO
MEAN TRIP TIME (MINUTES) BY ORIGIN

Figure 8.10

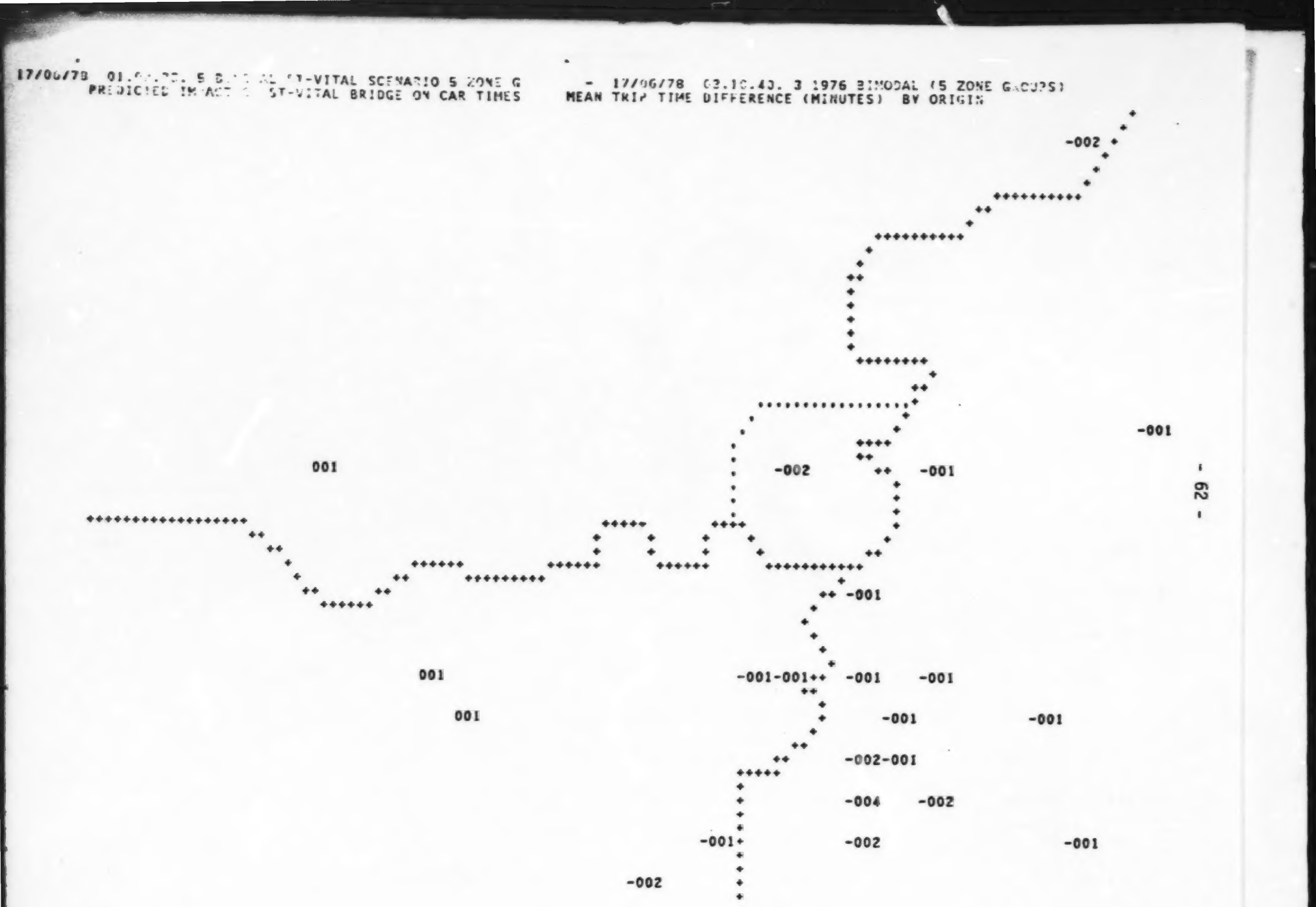

17/06/78 01.[illegible] 5 ZONE G
PREDICTED IMPACT [illegible] ST-VITAL BRIDGE ON CAR TIMES
- 17/06/78 03.10.43. 3 1976 BIMODAL (5 ZONE GROUPS)
MEAN TRIP TIME DIFFERENCE (MINUTES) BY ORIGIN
-002
-001
001
-002
-001
-001
001
-001-001
-001
-001
001
-001
-001
-002-001
-004
-002
-001
-002
-001
-002

Figure 8.11

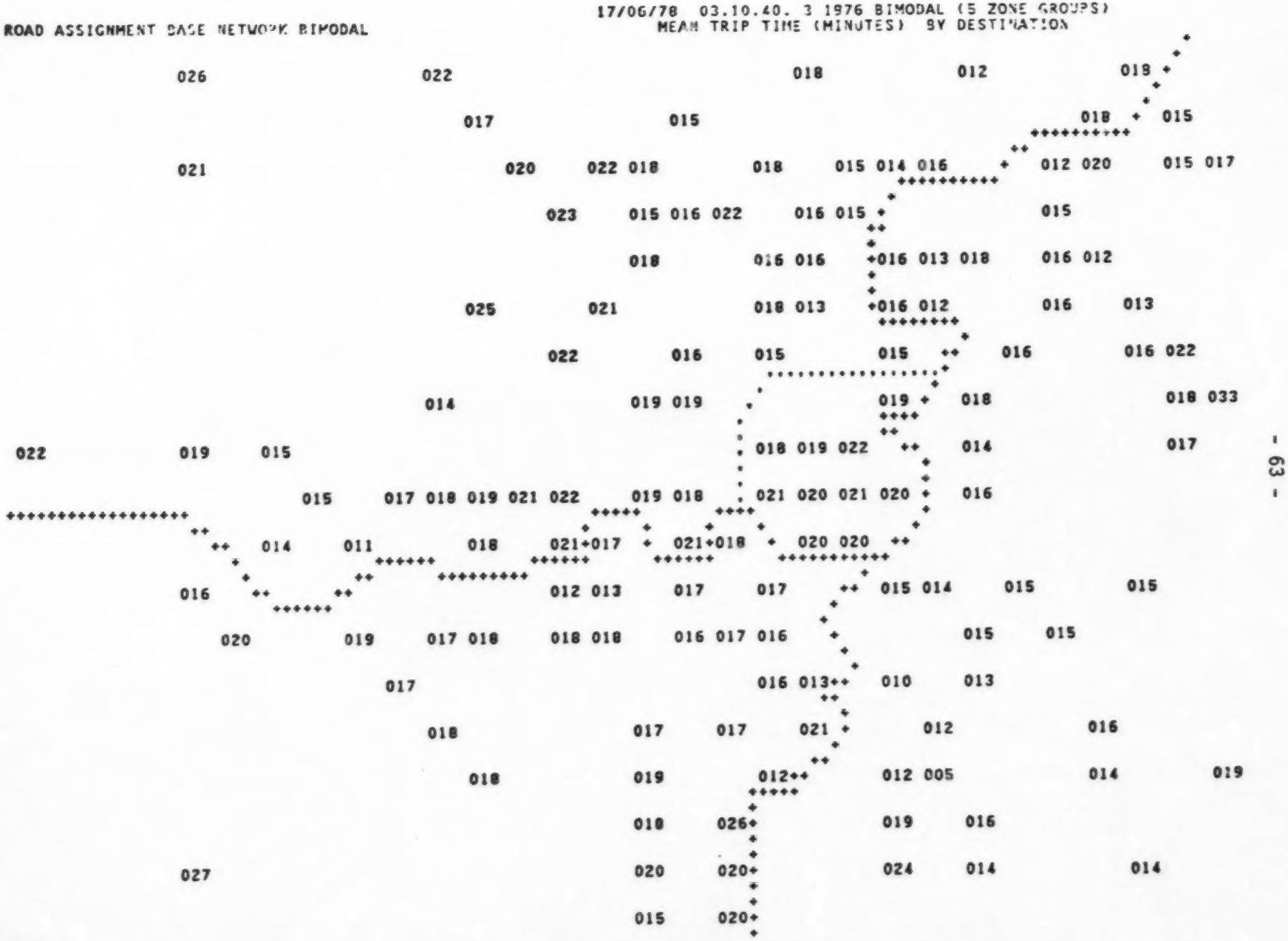

ROAD ASSIGNMENT BASE NETWORK BIMODAL
17/06/78 03.10.40. 3 1976 BIMODAL (5 ZONE GROUPS)
MEAN TRIP TIME (MINUTES) BY DESTINATION

Figure 8.12

17/06/78 01.02.23. 5 BIMODAL ST-VITAL SCENARIO 5 ZONE G - 17/06/78 03.10.40. 3 1976 BIMODAL (5 ZONE GROUPS)
. PREDICTED IMPACT OF ST-VITAL BRIDGE ON CAR TIMES MEAN TRIP TIME DIFFERENCE (MINUTES) BY DESTINATION

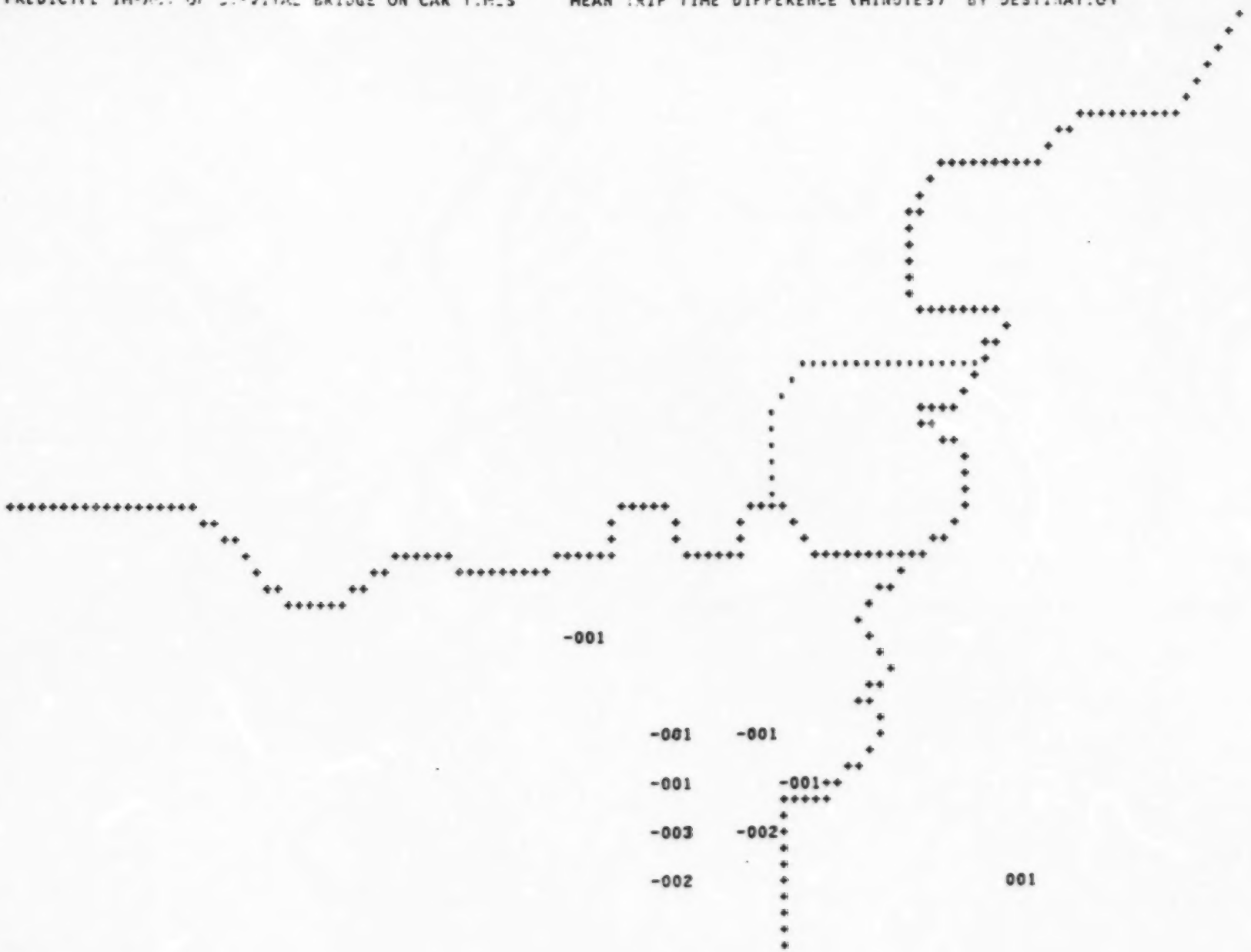


Figure 8.13

The volume on the bridges in the south-east wuadrant of the city are given in Table 8.5 below.

Bridges	Link	Hourly volume Before	After
Provencher	264- 871	2,017	2,002
Norwood	270- 356	3,022	2,842
St.Vital	306- 380	1,822	1,553
Fort Garry - St.Vital	1011-1060	-----	1,987
Perimeter	325- 423	1,109	68

Table 8.5

The computating times and costs for this scenario are as follows

Generate transit network	3.82
Calculate bus frequency	1.24
Calculate transit impedance	1109.58
Initialize road traffic demand	3.50
Perform road traffic assignment	2701.77
Modify transit link times	70.55
Calculate fixed transit demand	1.77
Calculate demand function (transit)	0.00
Perform transit assignment	425.33
Modify transit capacity	0.00

Central processor	$198.00
Input - Output	24.00
Fast memory	586.00
Total	$808.00

CONCLUSION

The main conclusion that we draw from this project is that the use of sophisticated models, such as EMME, is feasible and the simulation of scenarios results in refined and fully detailed evaluations which would not be possible otherwise. The main obstacles are the quality of the available data and the calibration of the demand model. Fortunately, we had access to very good data and we succeeded to calibrate a satisfactory modal split model.

While the costs of building up the necessary data base and calibrating the model are relatively high, the use of the model is not expensive. The figure of $800 for each bi-modal simulation is reasonable, when one considers that the analyst's time to set up a scenario and analyse the EMME output is of the order of one to two days.

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ACKNOWLEDGMENTS

We sould like to thank Ed Guertin and Jarvis Kohut of the City of Winnipeg for their precious collaboration and to the Transportation Research and Development Centre of Transport Canada for their financial support of this work.

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APPENDIX

The overall steps of the computational procedure are as follows:

Step 0: Select initial estimate of transit service levels $\bar{L}_s^{tr}$ (travel times) for all segments s such that $\Delta_{as} = 1$

Step 1: Compute shortest paths in the transit network and obtain transit service levels $\bar{L}_{pq}^{tr}$ for all (p,q)

Step 2: Solve an equilibrium problem on the road network using the demand functions $\tilde{G}_{pq}^{au}(L_{pq}^{au}, \bar{L}_{pq}^{tr})$ for all (p,q) and obtain the equilibrium demands, flows and service levels $\bar{L}_a = S_a(\bar{v}_a)$

Step 3: If the current transit service levels $\bar{L}_s^{tr}$ are significantly different than those given by relations (11), $\bar{L}_s^{tr} = c_s(\bar{L}_a$, if $\Delta_{a,s}=1)$, then replace $\bar{L}_s^{tr} \leftarrow \bar{L}_s^{tr}$ and return to Step 1. Otherwise continue to Step 4.

Step 4: Determine the transit demands

$$D_{pq}^{tr} = \tilde{G}_{pq}^{tr}(\bar{L}_{pq}^{au}, \bar{L}_{pq}^{tr}), \text{ all } (p,q)$$

and allocate these trips along the current shortest paths in the transit network.

The notation used is

$\bar{L}_s^{tr}$ - the travel time on line segment s of the transit network

$$\nabla_{as} = \begin{cases} 1 & \text{if road link } a \text{ coincides eith line segments} \\ 0 & \text{otherwise} \end{cases}$$

$\bar{L}_{pq}^{tr}$ - the travel time on the transit network between p and q

$\bar{L}_{pq}^{tr}$ - the travel time on the road network between p and q

$\tilde{G}_{pq}^{au}(L_{pq}^{au}, \bar{L}_{pq}^{tr})$ - the restriction of the demand functions with respect to the auto travel time L_{pq}^{au}

$\bar{L}_a$ - the travel time on link a of the road network

$C_s(\bar{L}_a, \text{ if } \Delta_{as=1})$ - bus/auto travel time functions for links and lines segments which coincide

D_{pq}^{tr} - the equilibrium demand by transit between p and q

$\bar{v}_a$ - the equilibrium flows of road link a.

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